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# ORIGINAL ARTICLES

## STUDIES IN THE TECHNIQUE OF FIELD EXPERIMENTS

### II. SAMPLING FOR STAPLE-LENGTH DETERMINATION IN COTTON TRIALS

**With a Note on the Standard Error of Estimates of Ginning Percentage**

ERRATA.

*Page 553*—

Table, sub-heading of column 4, *for* " Degrees of m " *read* " Degrees of freedom ".

Table, sub-heading of the last column, *insert* " I. P. I." before the words " poor land ".

*Page 565*, line 10 from bottom, *for* " hriry " *read* " hairy ".

*Page 573*, line 21, *insert* " , " after the word " small ".

*Page 588*, page number, *for* " 88 " *read* " 588 ".

*Page 614*, letterpress of Fig. 2, *for* " Regression ine " *read* " Regression line ".

[illegible] staple-length measurer.

It was known that the variance of the mean of ten halo-lengths is low, and it was hoped that it might be possible to reduce the number of measurements without seriously reducing the accuracy of the mean. No published information appeared to be available concerning variation in staple-length from plot to plot of the same variety. If variation between plots of a variety were of the same order as variation within plots, a satisfactory estimate of halo-length, together with a valid standard error, could be made from a single bulk sample of the produce of a variety, thereby saving the labour and storage accommodation involved in keeping separate samples from each plot.

Halo-lengths were measured on samples obtained from two randomised block experiments laid out on *barani* (unirrigated) land at Dhar and Limbodi (near Indore) in 1933. Five Indore selections and the local cotton (all Indian varieties) were tested in six blocks in each experiment, giving 36 plots per experiment. The soil at Limbodi was much less fertile than at Dhar and the yield of the Limbodi trial was further depressed by very late sowing.

Mean yields per acre were :—

| | |
|---|---|
| Dhar | 424 lbs. |
| Limbodi | 169 lbs. |

Only one picking was possible at Limbodi and the whole of the produce was available for lint-length sampling. At Dhar three pickings were taken, and the whole produce of each plot was thoroughly mixed and a sample drawn for staple-length determination.

Measurements were made on one side of each of ten combed seeds per sample, making 360 measurements per experiment.

Statistical analyses on a single measurement basis are given in Table I.

TABLE I

*Analysis of variance of halo-length measurements*

| | Degrees of freedom | Sum of squares | Mean square | $\frac{1}{2}\log_e$ |
|---|---|---|---|---|
| *Dhar*— | | | | |
| Blocks | 5 | 20 | 4·00 | 0·69 |
| Varieties | 5 | 486 | 97·20 | 2·29 |
| Between plots | 25 | 334 | 13·36 | 1·30 |
| Within plots | 324 | 407 | 1·26 | 0·12 |
| *Limbodi*— | | | | |
| Blocks | 5 | 50 | 10·00 | 1·15 |
| Varieties | 5 | 87 | 17·40 | 1·43 |
| Between plots | 25 | 309 | 12·36 | 1·26 |
| Within plots | 324 | 361 | 1·11 | 0·05 |

| | | Dhar | Limbodi |
|---|---|---|---|
| Between plots v. within plots | $z =$ | 1·18 | 1·21 |
| $n_1 = 25$, and $n_2 = 324$ | | | |
| $P = 0·01$ when $z$ is about 0·3 | | | |
| Blocks v. between plots | $z =$ | 0·61 | 0·11 |
| $n_1 = 25$, and $n_2 = 5$ | | | |
| $P = 0·05$ when $z = 0·76$ | | | |
| Varieties v. between plots | $z =$ | 0·99 | 0·17 |
| $n_1 = 5$, and $n_2 = 25$ | | | |
| $P = 0·05$ when $z = 0·48$ | | | |
| $P = 0·01$ when $z = 0·67$ | | | |

Significant differences between varieties exist in the Dhar data only.

In neither experiment was the lint-length variation between blocks as great as the variation between plots within blocks. Arrangement of plots in blocks, therefore, conferred no advantage in the comparison of halo-lengths. In both these experiments the variation in yield between blocks was very much larger than that between plots within blocks, showing that the causes of uncontrolled variation in lint-length are different from those in yield.

The mean square between plots represents the error mean square appropriate for testing the significance of varietal differences, while the mean square within plots represents the sampling error. In both experiments the error mean square was about ten times as large as the sampling error. Plot-to-plot differences are, therefore, responsible for the major portion of the error of halo-length determinations, and such determinations should, wherever possible, be made on each plot separately, and not on bulk samples. The standard error determined from the variation between measurements on seeds drawn from a bulk sample will therefore be a serious under-estimate. Such an estimate of the standard error was obtained by treating the whole of the observations in each of the two experiments under review as a single set of measurements for each variety. The two estimates of the standard error of the mean are compared below :—

| | Treated as bulk sample | Plot-wise (From Table I) |
|---|---|---|
| Dhar . . . . . | 0·19 | 0·47 |
| Limbodi . . . . . | 0·18 | 0·45 |

Table I shows quite clearly that the accuracy of comparisons of lint-length depends almost entirely on the number of plots available, and only to a very small extent on the number of measurements per plot.

Let $K$ be the variance of the mean of $N$ plots with $n$ measurements per plot. Then, if $p$ be the variance between plots due to soil differences, and $m$ be the variance between single measurements within a plot,

$$K = \frac{p + \frac{m}{n}}{N}$$

[Immer, 1932 ]

It is now possible to make a direct study of the effect of changes in number of measurements per plot or of number of replications on the accuracy of comparison

of staple-length measurements. In the experiments under discussion the following values were obtained :—

| | Dhar | Limbodi |
|---|---|---|
| $K = \frac{\text{Mean square (between plots)}}{Nn}$ | 0·223 | 0·206 |
| $m$ = Mean square (within plots) | 1·26 | 1·11 |
| $n$ | 10 | 10 |
| $N$ | 6 | 6 |
| $p = KN - \frac{m}{n}$ | 1·210 | 1·125 |

Changes in the number of measurements per plot ($n$) will only influence $K$ by changing the value of $\frac{m}{n}$, whereas changes in $N$ affect the value of $K$ directly. Since $m$ is approximately equal to $p$ in the present instance where $n = 10$, $\frac{m}{n}$ only contributes about 10 per cent of the value of $K$, and number of replications is the predominant factor in determining the value of $K$. Improvement in accuracy of comparison of staple-length measurements, therefore, can be gained rapidly by increasing the number of replications, but only very slowly and to a very limited extent by increasing the number of measurements per plot.

The number of replications in an experiment is primarily determined by considerations of agricultural convenience, and the size of the error permissible in yield comparisons. It is not usually possible to make $N$ greater than six or eight. The only question for consideration is the extent to which the labour of staple-length determination can be reduced by reducing the number of measurements per plot.

In Fig. I the effect of varying the number of measurements per plot on the variance of the mean of six plots is represented graphically. Calculations are based on the Dhar data.

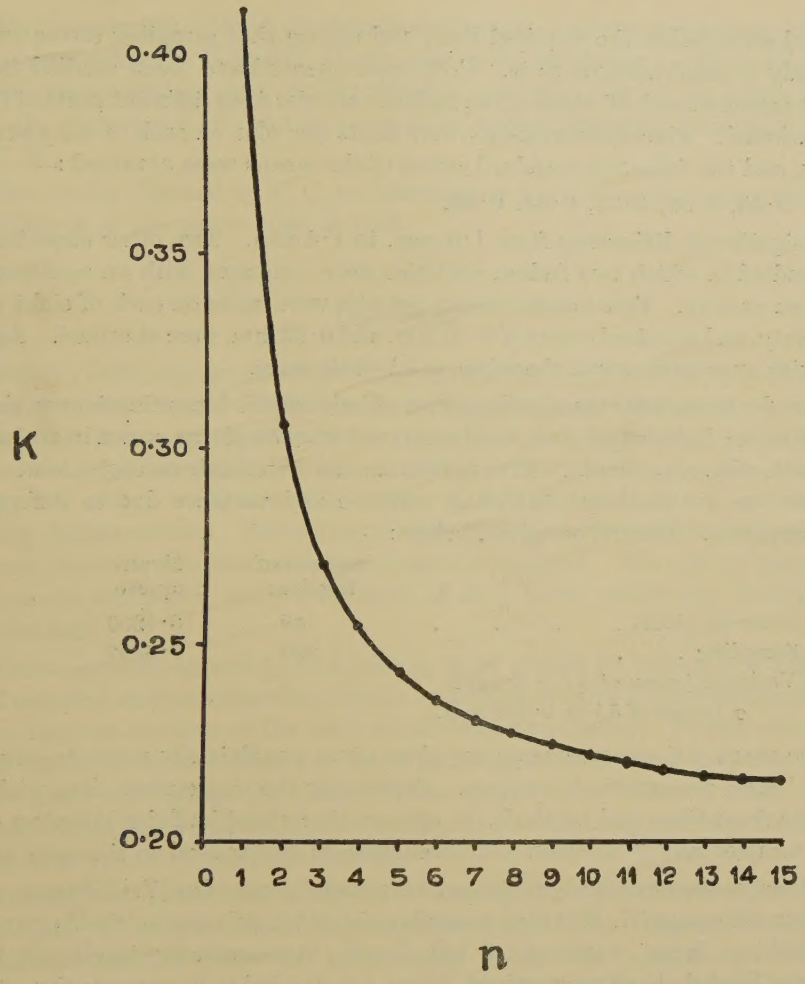


Fig. 1. Effect of changes in number of measurements per sample on variance of mean of six samples. Calculated from Dhar data.

Any increase in the number of measurements above ten reduces the variance of the mean (= $K$) very little, and a decrease in $n$ from ten to five only increases $K$ from 0·223 to 0·244, an increase of just over 9 per cent in variance, which corresponds to an increase of 4·3 per cent in standard error. Further reductions in $n$ lead to a rapid increase in $K$.

For practical purposes in variety testing, a significant difference of 1·5 mm. is all that is required. For such a difference to be significant, the standard error of the difference must be 0·75 mm. or less, corresponding to a standard error of the mean of 0·515 mm. or less. $K$ will then be $(0{\cdot}515)^2$ or 0·265. From Fig. 1, $K = 0{\cdot}265$ when $n$ is about 3·5. At that point the value of $K$ is increasing rapidly with decreases in $n$. Five measurements per sample should, however, give a

standard error below the required limit and ensure that sampling errors contribute only a small amount to it. Five experiments have been studied in the current season in each of which seven Indian varieties from different parts of India were included. Five measurements were made per plot on each of six plots per variety, and the following standard errors of the means were obtained :—

0·45, 0·39, 0·35, 0·44, 0·49,

giving significant differences from 1·0 mm. to 1·4 mm. Two other experiments were studied in which two Indian varieties were compared with an acclimatised American variety. Five measurements per plot were made on each of eight plots per variety, and standard errors of 0·50 mm. and 0·52 mm. were obtained. Agreement with expectation was, therefore, good in all cases.

In order to estimate the sampling error of halo-length determinations on single-plant samples, halo-length data were examined from 50 plants grown in an Indian cotton selection experiment. Five measurements were made on each plant. The variance was analysed into sampling variance and variance due to differences between plants. Results are given below :—

| | Degrees of freedom | Mean square |
|---|---|---|
| Between plants . . . . | 49 | 8·1250 |
| Sampling . . . . . | 200 | 0·6162 |

Variance (mean of 5) = 0·1232

$\sigma$ (mean of 5) = 0·351 mm.

The mean of 5 measurements per plant gives a sufficiently accurate estimate of halo-length for practical purposes. Comparing the single-plant data with the plot data from Dhar and Limbodi, it appears that about half the sampling error in plot samples may be ascribed to differences from seed to seed on the same plant.

All the measurements above quoted were made by one of us (V. G. Panse), or by one of our colleagues (N. S. Apte) on seeds combed by girls trained for the purpose. For making large numbers of halo-length measurements intelligent boys, literate in English, have been trained, and it was decided to investigate the standard error of their measurements and compare them with our own. Sets of five measurements on each of 50 plants were examined, as above. Below are given sampling variances for four observers, and the number of measurements required to give a variance of the mean equal to or less than 0·25 (corresponding roughly to a significant difference between means of 1·5 mm.) :—

| Observer | Sampling variance | No. of observations for $V$ ($M$) = 0·25 or less |
|---|---|---|
| K. G. (American) . . . . . | 3·702 | 15 |
| (Indian) . . . . . | 3·026 | 12 |
| D. U. . . . . | 1·541 | 6 |
| Y. U. . . . . | 1·094 | 5 |
| D. L. . . . . | 2·450 | 10 |

No observer has reached the standard of accuracy of our own figures, but the results obtained by D. U. and Y. U. are reasonably satisfactory. Since all observations were taken on very similar material, except those on American cotton by K. G., observers K. G. and D. L. must be judged definitely inferior to D. U. and Y. U.

The results obtained by K. G. on American and Indian cottons show that the variability is of the same order in both.

## Discussion

Bailey [1930] has described in detail the method of determining halo-length employed in the Sudan. While it is the primary purpose of this paper to discuss the error to which such measurements are subject, it is necessary to refer to the method of measurement employed. Combing is done in the way described by Bailey, but with a steel weaver's comb. A xylonite comb is not suitable for combing Indian cottons. Measuring is done with Bailey's celluloid staple-length measurer, but only the maximum halo-length is recorded. The edge of the halo is taken as the end point, and not the ends of stray hairs, which may be detached from the seed.

There does not appear to be anything to be gained by taking five measurements per seed, and reducing the average by a small amount to compensate for the shorter hairs at the base of the seed, as advocated by Bailey. In any case halo-length can never be an estimate of mean hair-length, as the vast majority of the shorter hairs must always be hidden by the longer ones. Since it must be an estimate of maximum hair-length, for facility of measurement and ease of training of staff, it should be as simple as possible.

Taylor [1930] states that in Nigeria, to obtain a degree of accuracy of 0·5 mm., it is necessary to comb and measure 50 seeds per plant. If by " degree of accuracy " is meant standard error of the mean, under the conditions of these experiments, five measurements per plant should be adequate with properly trained observers. For a significant difference of 0·5 mm., 20 to 25 measurements should be sufficient. It does not seem likely that under any conditions there will be much to be gained by aiming at a significant difference of less than 1 mm. For all ordinary purposes a significant difference of 1·5 mm. will be sufficient, and with properly trained observers this should be attained by taking the mean of five measurements per sample.

## Acknowledgments

We are indebted to Mr. N. S. Apte for the use of halo-length measurements made by him.

The material from which the Dhar and Limbodi data were obtained was supplied by the Superintendent of Agriculture, Dhar State, and the Registrar of Co-operative Societies, Holkar State, respectively, and we take this opportunity of offering them our thanks.

SUMMARY

1. Information was collected on halo-length, plot by plot, in replicated variety trials. Combing was done by girls trained for the purpose, and measurements were made by skilled observers.

2. Similar data was collected on halo-lengths of single plants. Combing was done by the same girls, but some sets of measurements were made by semi-skilled laboratory assistants.

3. It is shown that with skilled observers, five measurements per plot, or per plant, are adequate to give a standard error of the mean of 0·5 mm.

4. Laboratory assistants varied greatly in their efficiency as measured by the standard error of the means of their observations, indicating the necessity of careful training and periodical checking of such subordinate staff.

5. In replicated plot trials with measurements by skilled observers, within-plot variation was responsible for only a small proportion of the error variance. Sampling for staple-length measurement should, therefore, be plot-wise, and not from the pooled product of all plots of a variety.

REFERENCES

Bailey, M. A. (1930). Report and Summary of Proc., E. C. G. C. Conference on Cotton Growing Problems, p. 152.

Immer, F. R. (1932). *J. Agric. Res.* **44**, 633.

Taylor, C. B. (1930). Report and Summary of Proc., E. C. G. C. Conference on Cotton Growing Problems, p. 157.

## A Note on the standard error of estimates of ginning percentage in variety trials

It is not usually possible to arrange for the ginning of the produce of individual plots separately in variety trials, and there appear to be no records available from which an estimate can be made of the reliability of ginning percentages determined from ginning records of the total produce per variety in such trials.

The produce of five cotton variety trials, laid out in randomised blocks in the 1934-35 season, was ginned plot by plot and ginning percentages were treated by the method of the analysis of variance. The table below gives mean squares, standard errors of the mean, and significant differences for these experiments.

*Analysis of variance of ginning percentage*

| | 2 pairs of blocks | | Six blocks | | | | | Eight blocks | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Barwani | | | I. P. I. medium land | | I. P. I. poor land | | | I. P. I. medium land | poor land |
| | Degrees of freedom | Mean square | Degrees of m | Pickings 1 and 2 | 3rd picking | Pickings 1 and 2 | 3rd picking | Degrees of freedom | Mean square | Mean square |
| | | | | Mean square | Mean square | Mean square | Mean square | | | |
| Blocks . . | 2 | 0·20 | 5 | 0·13 | 1·17 | 2·6 | 0·61 | 7 | 1·65 | 0·36 |
| Varieties . . | 6 | 89·97 | 6 | 142·70 | 110·26 | 83·97 | 88·45 | 2 | 10·85 | 14·58 |
| Error . . | 12 | 0·36 | 30 | 0·18 | 0·65 | 4·24 | 1·16 | 14 | 1·14 | 0·11 |
| Standard error of mean | ... | 0·30 | ... | 0·17 | 0·33 | 0·84 | 0·44 | ... | 0·38 | 0·12 |
| Significant difference | ... | 0·90 | ... | 0·50 | 0·96 | 2·40 | 1·33 | ... | 1·00 | 0·35 |

As in the case of staple-length, differences between blocks were never greater than would be expected on random sampling only.

In all cases except Institute of Plant Industry poor land, a difference of one per cent in ginning outturn was significant. In the Institute of Plant Industry poor land experiment the total yield was very low, and 1st and 2nd pickings contributed only a small part of it. The land used in this experiment was very uneven and there were large differences in yield between plots.

## Summary

Where it is not possible to gin plot yields separately, the data here presented suggest that, provided the experiment was not carried out on very uneven land, a difference in ginning outturn of one per cent may be regarded with some confidence as real.

# STUDIES IN THE TECHNIQUE OF FIELD EXPERIMENTS

## III. AN APPLICATION OF THE METHOD OF COVARIANCE TO SELECTION FOR DISEASE RESISTANCE IN COTTON

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(Received for publication on 19th June 1935)

The analysis of covariance is being applied increasingly to the study of the effect of treatments on the yield of perennial crops. For this purpose plot yields are taken in a pre-experimental period, and the experimental yields are adjusted for the regression of experimental on pre-experimental yields [Eden, 1931; Murray, 1934]. Up to the present the method has not been of much use to workers with annual crops, since as great an advantage is not obtainable when it is not possible to use the same plants in the control and experimental periods. Such experience as is available indicates that a uniformity trial with an annual crop is not likely to increase the accuracy of the succeeding experiment by more than 60 per cent. For this increase the labour expended is doubled and the acquisition of the result postponed by a year [Fisher, 1934].

In the experiment to be described a uniformity test was superimposed on a variety trial. The loss of a season was thereby avoided, and the accuracy of the comparison between variety and uniformity plots increased by the elimination of seasonal differences.

In the course of a study, by the Baroda State Department of Agriculture, of methods of avoiding the damage to the cotton crop of Gujerat by root-rot disease, the authors were consulted as to the best method of testing the disease resistance of a number of selections from Gujerat varieties and from cultivators' fields in affected districts. Only a limited amount of land known to be heavily infected with the disease was available for experimental purposes, and inspection of data from non-replicated progeny row tests carried out in 1933-34 led to the conclusion that considerable variations in the intensity of attack might be expected within the area.

For the 1934-35 crop the material was divided into two experiments:—

| | | |
|---|---|---|
| (1) Strain No. 8 | (A) | Selections from the standard variety Broach 9. |
| Strain No. I 32/24 | (B) | |
| Strain No. I 65/12 | (C) | |

and

| | | |
|---|---|---|
| (2) District samples | (F) | Survivors from root-rot infested fields. |
| Broach 9 survivals | (G) | |
| Karakhadi survivals | (K) | |

Rozi and Broach 9, two Gujerat varieties, were included in both experiments. Each experiment was laid out in two 5×5 Latin squares, with 24 ft.×25 ft. plots. In each plot there were 8 rows 25 ft. long, each row containing 25 plants one foot apart. Of the 8 rows, alternate rows were sown with the susceptible control variety, Broach 9, giving four rows of control and four rows of the strain under test in each plot. In Broach 9 plots, of course, all 8 rows were of the same variety. Two rows of Broach 9 were sown all round the experiment as guard rows. The experiments were sown in May, six weeks before the onset of the monsoon, as it is known that the intensity of root-rot attack is much higher with early-sown than with rain-sown crops.

Deaths from root-rot were recorded row by row at intervals throughout the crop period. At the conclusion of the experiment percentage deaths were calculated separately for the control and varietal rows in each plot.

The rows of Broach 9, distributed in each plot in the same way as the rows of the strain under test, were expected to sample the same intensity of the disease as the strain, and the plot-to-plot variation in mortality in the strains was therefore adjusted for the mortality in the control rows by the application of the analysis of covariance.

The analysis of the results was carried out in four stages:—

(1) Analysis of variance of percentage deaths in variety rows in all plots.

(2) Analysis of variance of percentage deaths in control (Broach 9) rows in all plots.

(3) Analysis of covariance of percentage deaths in variety and control rows in the same plots.

(4) Analysis of variance of percentage deaths in variety rows adjusted by the covariance method for the mortality in control rows.

In Table I are given mean squares for error and for variety differences before and after adjusting for the covariance of control and variety mortality.

TABLE I

*Crude and adjusted mean squares due to error and to variety differences*

| Latin square | Mean percentage mortality in control | Error mean square | | Variety mean square | | Standard error percentage of mean | |
|---|---|---|---|---|---|---|---|
| | | Crude | Adjusted | Crude | Adjusted | Crude | Adjusted |
| I-a . . . | 65·3 | 179·0 | 98·6 | 1824·2 | 1559·5 | 11·6 | 8·6 |
| I-b . . . | 63·5 | 151·9 | 68·8 | 1328·2 | 818·2 | 11·3 | 7·6 |
| II-a . . . | 71·9 | 84·3 | 44·4 | 3305·7 | 2373·2 | 8·2 | 5·9 |
| II-b . . . | 45·4 | 119·7 | 88·5 | 698·2 | 714·0 | 15·6 | 13·4 |

In squares I-a, I-b, and II-a the mean square for error is reduced by the adjustment to approximately half the crude value. In square II-b the reduction in mean square is only about 25 per cent. In the first three squares the mean mortality in Broach 9 control rows was from 63 to 72 per cent, while in square II-b it was only 45 per cent. The efficiency of the method of covariance in reducing the error mean square depends upon the accuracy with which the control rows sample the disease intensity to which the variety rows are exposed. The data from square II-b indicate that with a lower disease intensity the agreement between variety and control rows is considerably reduced. This is illustrated by dividing the error sum of squares before adjustment into the parts contributed by: (1) regression of variety mortality on control mortality and (2) deviations from regression. Figures are given in Table II.

TABLE II

*Analysis of error sum of squares*

| | Degrees of freedom | Latin square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I-a | | I-b | | II-a | | II-b | |
| | | Sum of squares | Mean square | Sum of squares | Mean square | Sum of squares | Mean square | Sum of squares | Mean square |
| Regression . . . | 1 | 1063 | 1063 | 1066 | 1066 | 524 | 524 | 463 | 463 |
| Deviations from regression | 11 | 1085 | 98·6 | 757 | 68·8 | 488 | 44·4 | 974 | 88·5 |
| Crude error . . . | 12 | 2148 | ... | 1823 | ... | 1012 | ... | 1437 | ... |

In squares I-a, I-b, and II-a half or more than half of the original error sum of squares is accounted for by regression and half or less than half by deviations from regression, whereas in square II-b only about one-third of the original sum of squares is absorbed by regression, leaving two-thirds to deviations from it. The regression coefficients are in all cases significant.

When the experiments were laid out in pairs of Latin squares it was intended to combine the data from squares containing the same strains in order to improve the accuracy of comparison. Unfortunately, owing to an error, the same randomizations were used for both squares in the same pair, so that combination of the data is not strictly permissible. In order to obtain a comparison of the relative efficiency of doubling the number of plots, and of using the covariance of control rows with variety rows, in reducing the error variance, combined analyses were, however, calculated. Figures for standard errors per cent of means of five plots (variety rows only) in single squares and of ten plots (variety rows only) in combined squares are given below :—

| Latin square | Mean of 5 plots | | Mean of 10 plots |
|---|---|---|---|
| | Not adjusted | Adjusted | Combined not adjusted |
| I-a | 11·6 | 8·6 | 8·1 |
| I-b | 11·3 | 7·6 | |
| II-a | 8·2 | 5·9 | 7·8 |
| II-b | 15·6 | 13·4 | |

The covariance method has, on the average, given approximately the same statistical advantage as doubling the number of plots. It gives an advantage not given by doubling the number of plots in providing a local control where the attack of the disease is distinctly patchy. With independent randomizations in the pairs of squares, advantage could have been taken of both methods of reducing error.

The method of distributing control rows of a common variety through a series of variety plots is one to be used with discretion. Quite clearly, it cannot be used in yield-tests where varieties of considerably different habits of growth are under trial. It appears to have, however, very definite possibilities in testing a number of strains of rather similar growth habit, especially for characters,

such as disease resistance. It should have a particular appeal to the plant-breeder, who is often confronted with the need for making accurate comparisons between strains of which he has very limited amounts of seed.

## Summary

An experiment in an investigation of the resistance of cotton strains to root-rot disease is described, in which alternate rows of all plots were sown with a uniform control strain.

Details are given of the application of the method of covariance to the data obtained.

The error variance was in general reduced to about one-half by adjustment for the covariance of control and variety rows, giving the same advantage as would be obtained by doubling the number of plots.

The scope and advantages of the method are briefly discussed.

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# A PRELIMINARY NOTE ON THE CLASSIFICATION OF CULTIVATED INDIAN MUSTARDS

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## I. Introduction

The observations embodied in this paper are mainly confined to the classification of the cultivated Indian mustards into agricultural types. While examining the botanical characters of the cultivated Indian mustards grown from seeds from different parts of India in connection with their breeding work on the crop, the authors felt the necessity of such a classification. The previous workers had either touched only their botanical characters or grouped them into agricultural types in an imperfect manner.

Prain [1896], in his note on the mustards cultivated in Bengal, dealt with their botanical aspect only and classified them into species and varieties. His classification is valuable and is the only one of its kind on cultivated mustards. As it is, however, confined mainly to the crops grown in Bengal—the area now covered by the provinces of Bengal and Bihar and Orissa—it fails to be of much help in the classification of mustards cultivated in India as a whole. Besides, being a purely botanical classification, it cannot be used with advantage in the identification and isolation of numerous agricultural types which are so very common in *rai* and *sarson*.

Howard, Howard and Khan [1915] have discussed the biology of the mustards, and their observations form a valuable contribution to the study of this crop. Their classification of *Brassica juncea* into agricultural types affords useful information ; but at the same time it clearly shows the difficulties of grouping all the cultivated Indian mustards into a definite scheme. They have remarked that " the labour of reducing them (mustards) to paper is so great that no effort has been made to accomplish this exceedingly difficult task ". The authors are fully conscious of these difficulties and feel rather diffident of the result of their attempt. They have however endeavoured to present, in this paper, a scheme of classification which they hope will be helpful to the workers on this crop.

The authors obtained from different parts of India a large collection of seed samples of *B. nigra* Koch (Benarasi *rai*), *B. rugosa* Prain (Pahadi *rai*), *B. juncea* H. f. & T. (*rai*), *B. campestris* L. (*sarson*), *B. napus* L. (*tori*), and the pure lines isolated from the plants grown from these samples provided them with sufficient material for their work.

In this work, the classification of Prain has been fully taken into account and the changes that have been made in his nomenclature of varieties are with a view to make their names more suggestive of the principal distinguishing characters.

The authors are indebted to Messrs. C. E. Parkinson and M. B. Biswas for facilities to study the herbarium specimens of mustards at the Forest Research Institute, Dehra Dun, and the Royal Botanical Gardens, Calcutta, respectively, to Dr. F. J. F. Shaw for criticism and advice and to Dr. S. P. Agharkar and Mr. P. K. Dey for helpful suggestions.

## II. General plan of classification

Five species of cultivated Brassicas—*B. nigra* Koch, *B. rugosa* Prain, *B. juncea* H. f. & T., *B. campestris* L. and *B. napus* L.—are dealt with in this note.

*B. nigra* (Benarasi *rai*) and *B. napus* (*tori*) are almost self-sterile and widely cross-pollinated in nature. Among the plants raised from the seed samples of these two species, received from different parts of India, differences pertaining

to height and maturity, shape, size and colouration of the leaves, mode of branching, size and colour of the flowers were well marked ; but owing to their self-sterility and cross-pollination under natural conditions it was not possible to fix varieties or agricultural types of these species.

*B. rugosa* (Pahadi *rai*) is grown as a vegetable in the Kumaon hills. Its seed, it is reported, is also crushed for oil on a small scale for local consumption ; but it does not enter the trade in oil-seeds. As the crop is not of any importance in the agricultural industry, no attempt was made to fix its varieties or agricultural types.

*B. juncea* (*rai*) has been divided on the basis of hairs into two varieties—*Hirsuta* and *Glabra*. These are further subdivided into eleven agricultural types, eight under *Hirsuta* and three under *Glabra*, based on the time of maturity, height, branching, form of the leaf and colour of the seed-coat.

*B. campestris* L. (*sarson*) has been divided on the basis of the habit of the fruit into two varieties—*Erectisiliquosa* with ascending pods and *Pronisiliquosa* with pendant pods. Each of these varieties is subdivided into two groups—(1) 2-valved and (2) 3-4-valved. These groups are further classified on the basis of height, presence or absence of hairs on the stem and leaf, colour of the flower, shape of the fruit and colour and markings of the seed, into agricultural types—thirty-two under *Erectisiliquosa* and three under *Pronisiliquosa*. The *Pronisiliquosa* Type 33 with 2-valved pendant pods is based on the herbarium specimens from the Royal Botanical Gardens, Calcutta. It has been included in this note to make this classification somewhat complete.

## III. Key to the mustards

I. Pods appressed to the axis . . . . . *B. nigra.*

II. Pods spreading or semi-appressed to the axis.

A. Pods cylindrical and beaded ; and leaves tapering to the base.

(*a*) Leaves at the base persisting and forming a cluster. Stem scape-like . . . . . *B. rugosa.*

(*b*) Leaves at the base withering and not clustered. Stem normally branched . . . . . *B. juncea.*

(1) Leaves hairy . . . . . *B. juncea* var. Hirsuta.

*i.* Pods spreading.

(i) Flowers lemon-yellow.

(*α*) Margins of leaves green.

Tall, late . . . . . Type 1.

Tall, intermediate in maturity . . Type 2.

Intermediate in height and maturity . . Type 3.
Intermediate in height but early . . . Type 4.
Short, early . . . . . Type 5.

(β) Margins of leaves purplish.
Short, early . . . . . Type 6.

(ii) Flowers picric-yellow.
Short, early . . . . . Type 7.

*ii.* Pods semi-appressed to the axis.
Short, early . . . . . Type 8.

(2) Leaves glabrous . . . . . *B. juncea* var. *Glabra.*

*i.* Pods spreading; flowers lemon-yellow; margins of leaves green.
Tall, late . . . . . Type 9.
Intermediate in height and maturity . Type 10.
Intermediate in height but early . . Type 11.

B. Pods ascending or pendant, 2-4-valved. Stem-leaves auricled and stem-clasping . . . . *B. campestris.*

(*a*) Pods ascending . . . . . *B. campestris* var. *Erectisiliquosa.*

(1) Pods flat and 2-valved.

*i.* Flowers yellow; seed yellow.

(i) Plants hairy.

(α) Tall and late in maturity.

Lamina portion connecting the terminal lobe and uppermost lateral lobes folded inwards . . . . . Type 1.

Lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat . . . . . Type 2.

(β) Tall and intermediate in maturity.

Lamina portion connecting the terminal lobe and uppermost lateral lobes folded inwards . . . . . Type 3.

Lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat . . . . . Type 4.

(γ) Intermediate in height and late in maturity.

Lamina portion connecting the terminal lobe and uppermost lateral lobes flat . Type 5.

Lamina portion connecting the terminal lobe and uppermost lateral lobes irregular . . . . . Type 6.

(δ) Intermediate in height and maturity.

Lamina portion connecting the terminal lobe and uppermost lateral lobes narrow and flat . . . . . Type 7.

Lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat . . . . . Type 8.

(ε) Short and early in maturity.

Lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat . . . . . Type 9.

(ii) Plants glabrous.

Tall, late . . . . . Type 10.
Intermediate in height and maturity . Type 11.
Intermediate in height, early . . . Type 12.
Intermediate in height, late . . . Type 13.
Short, early . . . . . Type 14.

*ii.* Flowers yellow ; seed brown.

(α) Pods broad.

Intermediate in height and maturity . . Type 15.
Short, intermediate in maturity . . Type 16.
Short, early . . . . . Type 17.

(β) Pods narrow.

Short, intermediate in maturity . . . Type 18.

*iii.* Flowers naphthalene-yellow ; seed brown.

Short, early . . . . . Type 19.

Intermediate in height, late . . . Type 20.

(2) Pods cylindrical and 2-valved.

*i.* Flowers lemon-yellow ; seed yellow.

Intermediate in height, early . . . . Type 21.

*ii.* Flowers yellow ; seed brown.

(i) Leaves at the base not clustered. Stem normally branched.

($\alpha$) Plants hairy.

Late in maturity. Pods not beaded . Type 22.

Intermediate in maturity. Pods slightly beaded . . . . Type 23.

($\beta$) Plants glabrous.

Intermediate in maturity . . . Type 24.

(ii) Leaves at the base clustered. Stem scape-like.

Intermediate in height, late . . Type 25.

(3) Pods angled and 3-4-valved.

*i.* Flowers yellow ; seed yellow.

(i) Late in maturity.

Pods much inflated . . . . Type 26.

(ii) Intermediate in maturity.

($\alpha$) Beaks medium.

Pods slightly inflated . . . Type 27.

Pods very much inflated . . . Type 28.

($\beta$) Beaks long.

Tall ; pods slightly inflated . . Type 29.

Intermediate in height ; pods much inflated . . . . . Type 30.

($\gamma$) Beaks short.

Intermediate in height ; pods much inflated . . . . . Type 31.

*ii.* Flowers naphthalene-yellow ; seed yellow.

Short, early . . . . . Type 32.

(*b*) Pods pendant . . . . . *B. campestris* var. *Pronisiliquosa.*

(1) Pods flat and 2-valved.

*i.* Flowers yellow ; seed yellow.

Short, early . . . . . Type 33.

(2) Pods angled and 3-4-valved.

*i.* Flowers yellow ; seed yellow.

Tall, late . . . . . Type 34.

Short, early . . . . . Type 35.

C. Pods ascending, 2-valved, cylindrical and beaded. Stem-leaves auricled and stem-clasping . . *B. napus.*

## IV. Description of species and their varieties

### *Brassica nigra* Koch (*Benarasi rai*, *Mohari*, *Asal rai*, *Multani rai*)

This is a cold-weather crop grown to some extent in the United Provinces, Madras, Punjab and the North-West Frontier Province. Plants erect or bushy, very small-seeded, self-sterile, maturity of seed between 130 and 165 days. Height 120-250 cm. Stem slightly glaucous and green, branching usually above the base. Axillary angle between branches and the main axis 35° decreasing upwards to 20°. Stem-leaves non-stem-clasping, stalked, bristly hairy, lobed or pinnatisect, with lobes further incised in some cases, forming a cluster at the base, light or deep green, midrib white or purplish, margins undulated and dentate, 13-36 cm. long and 8-11 cm. wide. Leaves on floral shoots stalked, hairy, lanceolate, margins entire, 12-5 cm. long and 18-5 mm. wide. Inflorescence corymb, elongating into a raceme 50 cm. or more long. Bracts and bracteoles present in some plants. Pedicel 6-8·5 mm. long. Calyx light green and spreading in the young condition and picric-yellow and closed in the opened flowers. Sepals boat-shaped and hooded, 4 mm. long and 1 mm. wide. Corolla 1·2-1·5 mm. long, membranous and with a yellow midrib. Limb obovate or rounded with or without a notch at the apex, 4-5 mm. long and 3-4 mm. wide. Petals distinctly less broad than in other species. Stamens distinctly overtopping the stigma which just touches the base of the anthers. Outer stamens 4-5 mm. long. Inner stamens 5-6 mm. long. Ovary 2-3 mm. long. Style 1-1·5 mm. long. Stigma lemon-yellow and broad. Fruits cylindrical, beaded, 2-3 cm. long including stalk and beak, and appressed to the axis. Stalk 4-6 mm. long and beak 1-2 mm. long. Seed very small, ovoid, faintly rugose, brown.

### *Brassica rugosa* Prain (*Pahadi rai*)

Grown in the cold weather as a vegetable in the Kumaon hills. Root slender and tapering. Stem scape-like, stout, 100-125 cm. high with branches as high and forming a pyramidal head 25-35 cm. across. Radical leaves forming a cluster, ovate, narrowed to the base, not stem-clasping, thick, crumpled, green and glossy, bristly hriry, 40-70 cm. long, 14-30 cm. broad ; midrib white, thick, deeply channelled ; margins broadly dentate. Cauline leaves similar to radical leaves in shape but smaller in size, and tapering to a stalk-like condition towards the base, not stem-clasping, decreasing in size upwards. Inflorescence corymb, elongating into a raceme 5-10 cm. long in the flowering condition and increasing to 15-30 cm. during pod formation. Pedicels 5-7 mm. long, elongating to 1 cm. after fertilization. Sepals light green when young and changing to pale lemon-yellow before falling, sub-erect, boat-shaped, hooded, 5-6 cm. long and 1 mm. broad. Corolla lemon-yellow, 1 cm. across. Petals 6-6·5 mm. long. Claw 3-3·5 mm. long. Limb 2·5-3 mm. long and 2-3·5 mm. broad. Fruit 4-4·5 cm.

long, cylindrical, 2-valved, beaded, containing 10-16 seeds ; axillary angle between the pedicel and the floral axis 20°-30° ; stalk 7-10 mm. long ; beak 7-8 mm. long. Seed small, ovoid, brown, rugose, hilum white.

*Brassica juncea* H. f. & T. (*Gohna-sarson, Badshahi-Lai, Khas-rai*)

Root very stout and tapering. Leaves lyrately-lobed and narrowed to the base and not stem-clasping. Basal leaves quickly withering, green and a little glaucous. Stem elongating from the commencement of the growth and with purplish tinge at the nodes. Flowers lemon-yellow. Pods cylindrical, beaded, smooth, spreading or semi-appressed to the stem. Beak short. Seed dark brown or reddish brown or red, small and rugose.

*Brassica juncea* var. *Hirsuta* (*Nova*)

A cold-weather crop generally cultivated mixed with other crops throughout India. Height 75 to over 250 cm. Stem glaucous and green ; branched from the very base or little above the base ; axillary angle between branches and the main axis 45° decreasing upwards to 30°. Stem-leaves hairy ; stalk stout, broadened at base, furrowed on the upper surface and cylindrical below, upto 8·5 cm. long ; sinnuate lyrate, lobed or pinnatisect, lobes very unequal ; margin broadly toothed or serrate and uneven ; apex obtuse ; midrib white and slightly furrowed on the upper surface ; 27-49 cm. long and 15-20 cm. wide. Leaves on floral shoots stalked, small, triangular, lanceolate ; margin entire ; apex acute ; 11·5-2 cm. long and 7-1·5 cm. wide. Inflorescence corymb, 1-2·2 cm. long. Sepals light green and closed in buds, and yellow and spreading in the opened flowers, boat-shaped and hooded, 7 mm. long and 1·5 mm. wide. Corolla 1·7-1·8 cm. across. Claw membranous with a conspicuous yellow midrib, 4-5 mm. long. Limb 7-8 mm. long and 6 mm. wide, lemon-yellow. Outer stamens 6 mm. long and inner stamens 8 mm. long. Anthers recurved after bursting. Ovary 5 mm. long, green ; style 2 mm. long, green ; stigma lemon-yellow and capitate. Fruit spreading, 6·2 cm. long including stalk and beak, beaded, and cylindrical. Stalk 1·7 cm. long and beak 1·0 cm. long. Seed spherical or ovoid, smaller than that of *sarson* distinctly rugose, brown, deep brown or black.

*Brassica juncea* var. *2 Glabra* (*Nova*)

A cold-weather crop, generally cultivated mixed with other crops in most of the provinces in India. Height 135-205 cm. Stem glabrous, glaucous, green with or without a tinge of purple, branching from or above the base. Angle of branching 45° decreasing upwards to 30°. Branches more or less of equal length. Stem-leaves stalked, glabrous, green, sinnuate lyrate, 12-45 cm. long and 4-18 cm. wide ; margins broadly serrate ; midrib grooved and purplish sometimes.

Leaves on floral shoots glabrous, oblong-lanceolate to linear-lanceolate, margins entire, petiole with narrow wings in continuation of the lamina, 5·2-5 cm. long and 7-1·5 cm. wide. Inflorescence corymb, elongating into a raceme up to 60 cm. long. Pedicel up to 1 cm. Calyx light green and closed when young, and pale lemon-yellow and spreading in opened flowers. Corolla lemon-yellow, 1·5-1·7 cm. across. Claw 4 mm. long, membranous and with yellow midrib. Limb 7-8 mm. long and 7 mm. wide. Outer stamens 6 mm. long. Inner stamens 8 mm. long. Ovary 3-3·5 mm. long. Style 2-3·5 mm. long. Stigma lemon-yellow, broad and rounded, and flush with anthers in opened flowers before the anthers burst. Fruit, spreading, 5-6 cm. long including beak and stalk and 4 mm. broad, ridged along the replum and elliptical in cross section. Stalk 1·5 cm. Beak 9-11 mm. long. Seeds of the same size as in Hirsuta and smaller than that of *sarson*, ovoid, brown, with distinct black spot at the hilum and very rugose.

*Brassica campestris* L. (*Sarson, Pivli rai, Banga sarson, Shwet rai, Bara sarson, Pila sarson*)

Root stout and tapering; leaves glaucous, dark green and hairy beneath; cauline leaves auricled and stem-clasping; radical leaves smaller than cauline leaves and narrowed to the base and not stem-clasping; stem elongating from the commencement of growth and with purplish tinge in some cases, branching starting usually from the base; pods stout, 2-4-valved and spreading or semi-appressed; beak stout but short; seed brown or yellow, smooth and bold.

*Brassica campestris* L. var. *1. Erectisiliquosa* (*Nova*), *2-valved*

Plants belonging to this variety formed the major portion of the crop raised from *sarson* samples received from different parts of India and represent the *sarson* crop in the United Provinces. Height 75-175 cm. Stem glabrous or hairy, glaucous, green, branching from 6-10 cm. above the base. Stem-leaves glabrous or hairy, 28-18 cm. long and 15-4 cm. wide; sinnuate lyrate, dark green, stem-clasping; auricles rounded and extending half way on the opposite side of the stem; margins dentate. Leaves on floral shoots glabrous, glaucous, dark green, triangular-lanceolate, stem-clasping, 11·5 cm. long and 3·5-2 cm. wide; auricles rounded, surrounding the stem and overlapping; margins entire. Inflorescence corymb, elongating into a raceme. Flower stalked; pedicel 1·2 cm. long. Sepals keel-shaped, hooded, green and spreading when young and pale lemon-yellow and closed in opened flowers, 5 mm. long and 1 5 mm. wide. Corolla 1·5 cm. across. Claw membranous and pale lemon-yellow, 3 mm. long. Limb lemon-yellow, 7 mm. long and 5 mm. wide. Filaments dull green, 6 mm. long in the outer stamens and 8 mm. long in the inner stamens. Anthers yellow and recurved after bursting. Ovary stalked, style green and stout, stigma lemon-yellow. Fruit 2-valved, ascending flat or cylindrical, 12·5

cm. long including stalk and beak. Stalk 4·5 cm. long, and beak 2·5 cm. long. Seed ovoid, yellow or brown, large or small, smooth or faintly rugose, hilum distinct.

*Brassica campestris.* L var. *1. Erectisiliquosa (Nova), 3-4-valved*

Numerous specimens of this variety were found amongst plants raised from *sarson* seed samples which were received from the United Provinces, Bihar and Bengal. Height 75-175 cm. Stem glaucous, green, branching from the base. Stem-leaves hairy or glabrous, dark green, lyrately pinnatipartite, stem-clasping, 36-13 cm. long and 12-4 cm. wide ; auricles rounded and extending half-way on the opposite side of the stem ; margins broadly dentate. Leaves on floral shoots glaucous, dark green, glabrous, triangular-lanceolate, stem-clasping, 11-5 cm. long and 3·5-2 cm. wide ; auricles rounded, surrounding the stem, and overlapping ; margins entire. Inflorescence corymb, elongating into a raceme, 18 cm. long before pod formation and extending to 60 cm. after full development of the pods. Flower stalked ; pedicel 1·5-1·8 cm. Corolla 1·75 cm. across. Sepals keel-shaped and hooded, light green and spreading when young, pale lemon-yellow and closed when fading ; 7·5 mm. long and 2 mm. wide. Claw pale lemon-yellow, 5 mm. long ; limb lemon-yellow, 6 mm. long and 5 mm. wide. Stamens slightly overtopping the stigma ; filaments light green, 6 mm. long in the outer stamens and 7 mm. long in the inner stamens. Anthers yellow and recurved after bursting. Ovary stalked ; style green and stout ; stigma lemon-yellow. Fruit spreading and 3-4-valved, 12 cm. long including stalk and beak, stalk 5 cm. long and beak 2·5 cm. Seed large, ovoid, smooth, yellow ; hilum distinct.

*Brassica campestris* L. var. *Pronisiliquosa (Nova), 2-valved*

Height 130-175 cm. Stem glabrous, glaucous, green, branching from the base. Stem-leaves glabrous, sinnuate-lyrate, dark green, stem-clasping ; 28-18 cm. long and 15-4 cm. wide ; auricles rounded and extending half-way on the opposite side of the stem ; midrib on the upper surface, white with its lower portion channelled ; margin broadly dentate with teeth blunt. Leaves on floral shoot oblong-lanceolate or lanceolate, glabrous, glaucous, dark green and stem-clasping ; auricles rounded, surrounding the stem and overlapping. Inflorescence corymb, elongating into a raceme. Flower stalked ; pedicel 1·2 cm. ; sepals keel-shaped and hooded, green and sub-erect in young condition, and pale lemon-yellow and spreading in opened flowers. Corolla 1·5 cm. across. Petals clawed ; claw membranous, pale lemon-yellow, 3-5 mm. long ; limb lemon-yellow, 7-8 mm. long and 5 mm. wide. Filaments of outer stamens 6 mm. long and of inner stamens 7 mm. long. Anthers 2 mm. long. Ovary stalked. Style green, cylindrical and stout, 2 cm. long. Stigma lemon-yellow and capitate. Fruit 2-valved, flat, pendant, 11 cm. long including beak and stalk and 7 mm. wide. Stalk 2 cm. long ; beak 3 cm. long. Seed large, ovoid, yellow and smooth ; hilum distinct.

*Brassica campestris* L. var. *Pronisiliquosa* (*Nova*), *3-4-valved*

Numerous specimens of this variety were found amongst plants raised from *sarson* seed samples received from the United Provinces and Bihar.

Flower stalked, pedicel up to 2·3 cm. Sepals 5 mm. long and 1 mm. wide. Corolla 1·4 cm. across. Petals 8 mm. long; claw membranous with central portion yellow; limb lemon-yellow, 5 mm. long and 4 mm. wide. Fruit pendant, 3-4-valved, up to 10-12 cm. long including stalk and beak. Seed large, ovoid, yellow and smooth. Vegetative and other floral characters are almost the same as in var. *Erectisiliquosa*, 3-4-valved.

*Brassica napus* (*Tori, Toria, Lai, Dain, Laita, Sada rayee, Shurshi, Sanchi, Kale sarson*)

Largely grown in the Punjab, Bengal, Assam and the submontane tracts of the United Provinces. Plants shortest amongst the Indian mustards and almost self-sterile. Height 40-115 cm. Tap root slender and tapering. Stem, glaucous, green, glabrous or hairy, with or without purplish tinge in the upper part. Branching usually from the base. Branches shorter than the main stem. Stem-leaves sinnuate lyrate, dark green, generally glaucescent, glabrous or with few hairs on the veins in some cases; 33-13 cm. long and 13-6 cm. wide; auricles rounded and extending half-way round the stem, margins broadly dentate; midrib white and grooved above. Leaves on floral shoots glaucescent, glabrous, triangular-lanceolate, stem-clasping, 14-9 cm. long and 7-2 cm. wide, margins entire. Inflorescence corymb, elongating into a raceme. Pedicel usually glabrous or hairy in those cases where stems bear scattered recurved hairs. Sepals green and sub-erect when young and pale lemon-yellow and hooded. Petals clawed, lemon-yellow. Stamens flush with or overtopping the stigma. Style stout and green. Stigma naphthalene-yellow. Fruit 2-valved, cylindrical and beaded or flat and almost parallel to the axis, 11-4 cm. long. Seed smaller than that of *sarson*, dark brown, rugose; hilum not distinct.

## V. Distinguishing characters of the types of *Brassica juncea* and *Brassica campestris**

### *1. Brassica juncea*

*Type 1.*—Tall, late, robust; branching from the base; branches few; leaves large, very hairy, light green, crumpled, with terminal and lateral uppermost lobes turned inwards at the points of incision; flowers large; sepals light green; petals broad and lemon-yellow, pods spreading; seed dark brown and rugose.

* Plants 75-130-cm. high are termed short, 130-160 cm. high intermediate, and over 160 cm. tall. Plants maturing within 100-130 days are termed early, 130140 days intermediate, and over 140 days late.

*Type 2.*—Tall and intermediate in maturity; branching above the base; leaves smaller and less hairy than in Type 1, dark green, not crumpled, with uppermost incisions deep; flowers small; sepals light green; petals lemon-yellow, pods spreading; seed black and rugose.

*Type 3.*—Intermediate in height and maturity; branching above the base; leaves less hairy and smaller than in Type 2, elongated, dark green, not crumpled, with uppermost incisions deep; flowers small; sepals light green; petals lemon-yellow; pods spreading; seed dark brown and rugose.

*Type 4.*—Intermediate in height but early; branching above the base; leaves less hairy and smaller than in Type 2, elongated, dark green, not crumpled, with uppermost incisions deep; flowers small; sepals light green; petals lemon-yellow; pods spreading; seed dark brown, rugose.

*Type 5.*—Delicate; very short, very early; branching above the base; leaves small, hairy, with incisions deep; flowers very small, sepals light green; petals lemon-yellow; pods spreading; seed dark brown, rugose.

*Type 6.*—Short, early, delicate, purplish; branching above the base; leaves small, hairy, with margins dark purplish and folded inwards; flowers very small; sepals light green; petals pale lemon-yellow; pods spreading; seed dark brown, rugose.

*Type 7.*—Short, early, purplish, delicate, hairy; branching from the base, branches many and shorter than the main stem, bearing both radical and cauline leaves; radical leaves forming a cluster at the base, very hairy, deeply many-lobed; midrib and stalk purple; cauline leaves very hairy, deeply many-lobed; leaves on the floral axis short, narrow, elongated, with margins entire or minutely serrated; flowers small, sepals purplish, petals picric-yellow, small, narrow and veins at the base reddish; pod cylindrical, beaded and not much spreading; seed medium, ovoid, dull brown and faintly rugose.

*Type 8.*—Short, early; branching above the base; pods semi-appressed; other characters as in Type 3.

*Type 9* —Tall, late, robust; branching above the base; leaves large, glabrous, with upper incisions shallow; flowers large; sepals light green; petals broad and lemon-yellow; pods spreading; seed medium, brown, very rugose.

*Type 10.*—Intermediate in height and maturity; vegetative characters as in Type 9; flowers small, sepals light green; petals broad and lemon-yellow; seed medium, brown, very rugose.

*Type 11.*—Intermediate in height but early. Vegetative and floral characters as in Type 9.

### 2. *Brassica campestris* L.*

*Type 1.*—Tall, late, robust, branching from the base and early ; leaves large, hairy, crumpled, dark green and shining, midrib white, terminal lobe rounded, lamina portion connecting terminal lobe and uppermost lateral lobes folded inwards ; flowers large ; petals pale lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 2.*—Tall, late, robust, branching from the base, and about the time of formation of flower buds ; leaves large, hairy, dark green and dull, expanded, midrib white, terminal lobe oblong, lamina portion connecting the terminal and uppermost lateral lobes broad and flat ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 3.*—Tall, intermediate in maturity, branching from the base, leaves large, hairy, dark green and dull, fully expanded, midrib purplish, terminal lobe ovate, lamina portion connecting the terminal and uppermost lateral lobes somewhat folded inwards ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 4.*—Tall and intermediate in maturity, branching from the base ; leaves small, hairy, dark green and dull, expanded, midrib white, terminal lobe ovate or oblong, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 5.*—Intermediate in height, late, robust, bushy, branching from the base and early ; leaves large, hairy, somewhat crumpled, dark green and dull, midrib white, terminal lobe ovate, lamina portion connecting the terminal lobe and uppermost lateral lobes irregular and flat, flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 6.*—Intermediate in height, late, robust, branching from the base; leaves large, hairy, dark green and dull, somewhat crumpled, midrib white, terminal lobe ovate, lamina portion connecting the terminal lobe and uppermost lateral lobes irregular ; flowers large, petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, beaded, beaks long ; seed smooth, yellow, bold.

*Type 7.*—Intermediate in height and maturity, robust ; branching from the base ; leaves small, hairy, dark green and dull, expanded, midrib white, terminal lobe ovate, lamina portion connecting the terminal lobe and uppermost lateral lobes very narrow and flat ; flowers small ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long broad, smooth ; seed smooth, yellow, bold.

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*Plants 75-120 cm. high are termed short, 120-150 cm. high intermediate and 150-175 cm. tall. Plants maturing within 100-130 days are termed early, 130-140 days intermediate, and 140-150 days late.

*Type 8.*—Intermediate in height and maturity, stem purplish ; branching from the base, main shoot and branches flowering simultaneously ; leaves deep green, hairy, dull and expanded, terminal lobe triangular, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers large ; petals lemon-yellow, pods spreading, ascending, flat, 2-valved, long, broad smooth ; seed smooth, yellow, bold.

*Type 9.*—Short, early, stem thin, delicate and purplish ; branching from the base ; main shoot and branches flowering simultaneously ; leaves deep green, dull and expanded, terminal lobe elongated and ovate, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers small ; petals picric-yellow ; pods spreading, ascending, flat, 2-valved, short, narrow, smooth, and not much spreading ; seed smooth, yellow, bold.

*Type 10.*—Tall, late, robust ; branching late and about the time of formation of flower buds ; leaves large, glabrous, dark green, dull and expanded, midrib white, terminal lobe oblong, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, broad, smooth ; seed smooth, yellow, bold.

*Type 11.*—Intermediate in height and maturity, branching late and about the time of formation of flower buds ; leaves medium in size, glabrous, deep green, dull and expanded, midrib purplish, terimnal lobe triangular or ovate and elongated, lamina connecting the terminal and the uppermost lateral lobes broad and flat ; flowers large, petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, yellow, bold.

*Type 12.*—Intermediate in height, early ; other characters as in Type 11.

*Type 13.*—Intermediate in height, late ; leaves large glabrous. deeply lobed, succulant, emerald green and glossy, terminal lobe large, ovate to rounded ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, spreading, long, narrow, smooth ; seed smooth, yellow, bold.

*Type 14.*—Short, early, glabrous ; stem thin, delicate, purplish ; branching from the base, main shoot and branches flowering simultaneously ; leaves small, glabrous, green, dull, and expanded, terminal lobe elongated and triangular, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers large ; petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth, inflated when mature ; seed smooth, yellow, bold.

*Type 15.*—Intermediate in height and maturity, hairy ; stem stout and purplish ; branching from the base and late ; leaves large, deeply lobed, deep green and dull, midrib purplish, terminal lobe broadly ovate ; flowers large, petals lemon-yellow, pods spreading, ascending, flat, 2-valved, long, beaded, broad ; seed faintly rugose, brown, bold.

*Type 16.*—Short, intermediate in maturity, glabrous ; stem purplish ; branching above the base, main shoot and branches flowering simultaneously ; leaves dark green and dull, terminal lobe triangular ; flowers large, petals lemon-yellow ; pods spreading, ascending, flat, 2-valved, long, broad, smooth, dull green, semi-appressed ; seed smooth, brown, bold.

*Type 17.*—Short, early, glabrous ; stem purplish; leaves entire, emerald green and glossy ; flowers large, petals pale lemon-yellow, pods spreading, ascending, flat, 2-valved, long, broad, smooth ; seed smooth, brown, bold.

*Type 18.*—Short, intermediate in maturity, glabrous ; lower leaves irregularly lobed ; flowers large, petals lemon-yellow, pods narrow, short, shining, not much spreading, ascending, flat, 2-valved ; seed smooth, brown, bold.

*Type 19.*—Short, early and glabrous ; stem delicate purplish ; branching above the base, main shoot and branches flowering simultaneously ; leaves runcinate, succulent, deep green and dull, margin entire ; flowers small ; petals naphthalene-yellow, pods spreading, ascending, flat, 2-valved, long, broad, smooth, semi-appressed ; seed faintly rugose, brown, bold.

*Type 20.*—Intermediate in height, late, robust, glabrous ; stem purplish ; branching from the base but late ; leaves large, slightly succulent, deep green and glossy, irregularly deeply lobed, slightly crumpled, midrib purplish, terminal lobe broadly ovate, lamina portion connecting the terminal lobe and uppermost lateral lobes broad and flat ; flowers small, petals naphthalene-yellow, pods spreading, flat, 2-valved, long, very narrow, beaded ; seed faintly rugose, brown, bold.

*Type 21.*—Intermediate in height, early, glabrous ; leaves large, succulent, pale green and dull ; flowers very large ; petals lemon-yellow ; pods spreading, ascending, cylindrical, 2-valved, long, slightly beaded ; seed small and smooth, yellow.

*Type 22.*—Intermediate in height, late and hairy ; leaves large, lyrate, light green and glossy, terminal lobe rounded ; flowers large ; petals lemon-yellow ; pods long, not beaded, spreading, ascending, cylindrical, 2-valved ; seed faintly rugose, brown, small.

*Type 23.*—Intermediate in height and maturity and hairy ; stem purplish, branching from the base, main stem and branches flowering simultaneously ; leaves lyrate, green and dull ; flowers small ; petals lemon-yellow ; pods spreading, ascending, cylindrical, 2-valved, long, slightly beaded ; seed small, faintly rugose, brown.

*Type 24.*—Intermediate in height and maturity, robust and glabrous ; leaves large, irregularly deeply lobed, light green, terminal lobe elongated and ovate ; other characters as in Type 22.

*Type 25.*—Intermediate in height, late, very hairy ; radical leaves forming clusters, deep purple, bristly hairy ; flowering shoot purplish, hairy, scape-like ; flowers large ; petals pale lemon-yellow ; pods spreading, ascending, cylindrical, 2-valved, long, beaded ; seed small, smooth, brown.

*Type 26.*—Intermediate in height, late, robust, purplish, hairy ; branching from the base, main shoot and branches flowering simultaneously ; leaves succulent, deep green and dull, midrib purplish, terminal lobe oblong-ovate ; flowers large ; petals lemon-yellow ; pods spreading, ascending, 3-4-valved, long, inflated ; beaks long ; seed faintly rugose, yellow, bold.

*Type 27.*—Intermediate in height and maturity, robust, purplish, hairy ; branching from the base ; leaves large, oblong-ovate, deep green and dull, midrib purplish ; flowers large ; petals pale lemon-yellow ; pods with short stalks, slightly inflated, spreading ; ascending, 3-4-valved ; seed smooth, yellow, bold.

*Type 28.*—Pods with long stalks, very much inflated ; other characters as in Type 27.

*Type 29.*—Tall, intermediate in maturity, purplish, glabrous ; branching from the base ; leaves small, green and dull, terminal lobe ovate ; flowers large ; petals pale lemon-yellow ; pods spreading, ascending, 3-4-valved, long, slightly inflated ; beaks long ; seed smooth, yellow, bold.

*Type 30.*—Intermediate in height and maturity, purplish, glabrous ; branching above the base, main stem and branches flowering simultaneously ; leaves small, light green and dull, terminal lobe ovate ; flowers large ; petals lemon-yellow ; pods spreading, ascending, 3-4-valved, long, much inflated ; beaks long ; seed smooth, yellow, bold.

*Type 31.*—Intermediate in height and maturity ; pods very much inflated ; beaks short ; other characters as in Type 29.

*Type 32.*—Short, early, robust, purplish, glabrous ; branching from the base and early ; leaves large, green and dull, terminal lobe oblong-ovate ; petals naph thalene-yellow ; flowers small ; pods long, spreading, ascending, 3-4-valved, inflated ; beaks long ; seed smooth, yellow, bold.

*Type 33.*—Short, glabrous, early ; leaves deep green and dull ; flowers large ; petals lemon-yellow ; pods long, pendant, flat, 2-valved, broad, smooth ; seed smooth, yellow, bold.

*Type 34.*—Tall, late, robust, purplish and hairy, branching from the base and early ; leaves large, dark green and dull, terminal lobe rounded ; flowers large ; petals lemon-yellow ; pods very long, pendant, 3-4-valved, inflated and with long stalk ; seed smooth, yellow, bold.

*Type 35.*—Short, early, robust, purple, glabrous, branching above the base and late ; leaves large, green and dull, terminal lobe oblong-ovate ; flowers large, petals pale lemon-yellow ; pods long, pendant, 3-4-valved, inflated, beaded ; beaks long ; seed smooth, yellow, bold.

## VI. Summary

1. A general plan of the classification of cultivated Indian mustards, belonging to *Brassica nigra* Koch, *Brassica rugosa* Prain, *Brassica juncea* H. f. & T., *Brassica campestris* L. and *Brassica napus* L. is presented.

2. A key to the mustards is worked out.

3. The species and their varieties are described and the distinguishing characters of the types of *Brassica juncea* and *Brassica campestris* are given.

4. A few observations on the method of sowing, flowering and pollination are recorded in Appendix I.

5. The localities from where the original seed samples were obtained are noted in Appendix II.

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## VIII. Appendix I

### Observations on the method of sowing, flowering and pollination

The biology of the mustards has been adequately described by Howard, Howard and Khan [1915] and observations in this paper are confined to a few additional remarks which may be useful to scientific workers on this crop.

Mustards, especially *Brassica nigra*, do not tolerate deep sowing. When sown in deep furrows made by the plough, they do not germinate uniformly. The best results are obtained by sowing the seeds in shallow furrows 1-2 inches deep. Germination in this case is very uniform and quick.

The time of flowering and maturity varies in different mustards. Though they were all sown on the same date (16th October), the *tori* and some of the early types of *rai* were the first to mature. The *tori* plants began to flower from the 14th November when they were only about 9 inches in height and became ready for harvesting from the 1st February. Some of the types of *rai* (Types 5, 6 and 8) ripened early and were harvested about the same time as *tori*. The *sarson* varieties were next to mature. They commenced flowering from the 25th November and some of the early types (Nos. 9, 14, 19, 21, 32, 35) were ready for harvesting about the 7th February. The late types *rai* and *sarson* took about 140-150 days to complete their growth. *Brassica rugosa* was the last to mature amongst the mustards. These plants flowered about the same time as late *rai* and *sarson* but were not ready for harvest before the end of March.

A number of plants belonging to *B. nigra* (Benarasi *rai*), *B. rugosa* (Pahadi *rai*) and *B. juncea* (*Rai*), *B. compestris* (*sarson*), *B. napus* (*Tori*) were bagged to obtain self-pollinated seeds and also to study the extent of natural cross-pollination in these plants. In *tori* and Benarasi *rai* only a few seeds were obtained from each of the bagged plants which shows that these mustards are almost self-sterile and natural cross-pollination predominates in them. On the other hand the bagged plants of *sarson* and *rai* form seeds freely and appear to be naturally self-pollinated. A certain amount of cross-pollination would, however, be expected in these mustards through the bees which visit the flowers in large numbers.

## IX. Appendix II*

### Places from where the original seed samples were obtained

*1. Brassica nigra*

North-West Frontier Province :—Peshawar, Tarujabba 365, 366. Punjab :—Lyallpur 546. United Provinces :—Etawah 544 ; Moradabad, Bilari 550 ; Jaunpur 551 ; Pilibhit 359, 360 ; Atraula 543 ; Bareilly 545 ; Mirzapur 352, 353, 374. Madras :—Bezwada, Krishna-Lankas 547 ; Krishna, Chalapalli 548 ; Ganjam, Berhampur 549.

*2. Brassica rugosa*

United Provinces :—Kumaon hills, Almora 716, 717, 718.

*3. Brassica juncea*

*Type 1.*—Punjab :—Lyallpur 518, 519. United Provinces :—Sitapur 493, 494 ; Mirzapur 496, 497, 554 ; Aligarh 495, 553 ; Bahraich 506, 508 ; Allahabad 515, 542 ; Etawah 505 ; Rura 514 ; Bengal :—Maida 531 ; Dacca 534, 575. Bombay :—Gujrat, Dao (Dolka) 507. Madras :—Ganjam, Berhampur 520.

* The numbers refer to the herbarium sheets and the names of places to the sources from which the original seed samples were obtained.

*Type 2.*—United Provinces :—Benares 510, 511 ; Fyzabad 512, 513 ; Bahraich 504 ; Kulpahad 523 ; Mainpuri 529, 530. Bihar and Orissa :—Sabour 524. Bengal :—Tipperah 536.

*Type 3.*—United Provinces :—Partabgarh—Darwa market 498, 499 ; Maholi 500, 501 ; Gonda 502, 503. Bihar and Orissa :—Sabour 525 ; Patna 537.

*Type 4.*—Bihar and Orissa :—Sabour 526. Bengal :—Dacca 534, 575 ; Barisal 516, 517. Madras :—Ganjam, Aska 521.

*Type 5.*—Bengal :—Rangmati 535 ; Twenty four Parganas, Barasat 540, 541.

*Type 6.*—Bengal :—Chittagong, Ramu 538, 539.

*Type 7.*—Punjab :—Lyallpur 719, 720, 724.

*Type 8.*—Bengal :—Rangpur 533.

*Type 9.*—Punjab :—Lyallpur 568, 569. United Provinces :—Benares 563 ; Fyzabad 564, 565 ; Aligarh 578 ; Rura 567. Bengal :—Maida 574.

*Type 10.*—United Provinces :—Partabgarh, Darwa market 555, 556, 558. Madras :—Ganjam, Berhampur 570, 571.

*Type 11.*—United Provinces :—Partabgarh 552 ; Maholi 559, 560, 561, 562 ; Fyzabad 566 ; Jaunpur 577. Bihar and Orissa :—Patna 576. Madras :—Ganjam, Aska 572, 573.

*4. Brassica campestris*

*Type 1.*—United Provinces :—Aligarh 582, 583.

*Type 2.*—United Provinces :—Rura 599, 600.

*Type 3.*—Punjab :—Lyallpur 615, 616.

*Type 4.*—United Provinces :—Atarra 603 ; Kulpahad 619 ; Hardoi 626, 627, 628, 629.

*Type 5.*—United Provinces :—Etawah 593, 594.

*Type 6.*—United Provinces :—Cawnpore 601.

*Type 7.*—Bombay :—Ahmadabad, Paranty 609, 610.

*Type 8.*—United Provinces :—Mirzapur 584, 585 ; Allahabad 605, 606. Bengal :—Barisal 611, 612.

*Type 9.*—Bengal :—Birbhum 638.

*Type 10.*—United Provinces :—Mainpuri 630 ; Cawnpore 602 ; Atarra 604.

*Type 11.*—United Provinces :—Kulpahad 726 ; Atraula 586, 587.

*Type 12.*—United Provinces :—Gonda 588, 589.

*Type 13.*—United Provinces :—Bareilly 647.

*Type 14.*—United Provinces :—Bijnor 640. Bihar and Orissa :—Patna 642, 643. Bengal :—634, 635, Birbhum 637, 639.

*Type 15.*—United Provinces :—Sitapur 713.

*Type 16.*—United Provinces :—Benares 598 ; Jaunpur 644.

*Type 17.*—United Provinces :—Partabgarh, Maholi 645.

*Type 18.*—United Provinces :—Benares 597.

*Type 19.*—United Provinces :—Partabgarh, Maholi 646.

*Type 20.*—United Provinces :—Partabgarh, Maholi 648 ; Kulpahad 725. Bihar and Orissa :—Ranga 625.

*Type 21.*—United Provinces :—Etawah 592.

*Type 22.*—United Provinces :—Rura 721. Punjab :—Lyallpur 617.

*Type 23.*—United Provinces :—Atarra 650.

*Type 24.*—Punjab :—Lyallpur 618.

*Type 25.*—North-West Frontier Province :—Peshawar, Tarujabba 489, 490, 491, 492, 715.

*Type 26.*—United Provinces :—Sitapur 714.

*Type 27.*—United Provinces :—Sitapur 579 ; Lakhimpur 580 ; Bareilly 613, 614. Bihar and Orissa :—Sabour 621.

*Type 28.*—United Provinces :—Bareilly 722.

*Type 29.*—United Provinces :—Lakhimpur 581.

*Type 30.*—United Provinces :—Pilibhit 607, 608.

*Type 31.*—United Provinces :—Bahraich 590, 591.

*Type 32.*—Bihar and Orissa :—Sabour 621.

*Type 33**.—Bengal :—Calcutta, Sibpur Experimental Farm, Cultivated (Prain 481).

*Type 34.*—United Provinces :—Lakhimpur, Gola Gokarannath 595, 596.

*Type 35.*—Bihar and Orissa :—Ranga 623.

### *5. Brassica napus*

Punjab :—Lyallpur 723. United Provinces :—Sitapur 653, 654, 655, 706 ; Mirzapur 50, 182, 183, 184, 676 ; Kulpahad 686, 687, 688; Atarra 87, 88, 89, 90 ; Jaunpur 80 ; Lakhimpur, Gola Gokarannath 79, 682, 710 ; Gonda 76, 185, 186, 679 ; Atraula 122, 181, 677, 678 ; Bahraich 70, 71, 680, 681 ; Nanpara 82, 84, 85, 86, 683 ; Partabgarh 17. Bihar and Orissa :—Ranga 100, 101, 102, 103, 104, 689. Bengal :—Dacca 150, 151, 152, 698, 700 ; Dinajpur 155, 156, 157, 691, 693, 694 ; Rangamati 114, 115, 116, 117 ; Maida 105, 106, 109, 690 ; Birbhum 161, 162, 701, 702 ; Twenty-four Parganas, Basirhat 163, 164, 165 ; Tipperah 168, 169, 170, 703 ; Krishnanagar (Nadia) 173, 174, 175, 704 ; Chittagong, Ramu 176, 177, 178, 179, 180 ; Barisal 705. Assam :—Sylhet 1, 13, 27, 35, 43, 62, 670, 671, 672, 707, 708, 709 ; Gauhati 51, 52, 53, 54, 55, 56, 675 ; Sibsagar 57, 58, 59, 60, 61, 673, 674. Madras :—Ganjam, Aska 95, 96, 97, 98, 99, 685 ; Berhampur 684.

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*Based on the herbarium specimens from the Royal Botanical Gardens, Calcutta.

# SOME SOIL-HETEROGENEITY TRIALS AT PUSA AND THE SIZE AND SHAPE OF EXPERIMENTAL PLOTS

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(With four text-figures)

## I. SOIL-HETEROGENEITY TRIALS

In theory, field trials should be conducted under uniform conditions of soil and culture. This, however, is an unattainable ideal since an absolutely uniform piece of land hardly exists in nature and therefore methods must be adopted which lessen or eliminate the effects of soil-heterogeneity. Fields which from inspection appeared satisfactorily uniform have been shown by Harris [1915] and many others to be very heterogeneous in some cases, and the extent to which even a small field can show variations in fertility is demonstrated by the present results of uniformity trials conducted at Pusa.

A field about one-fourth of an acre in area was sown in three consecutive years with Pusa barley Type 21, Pusa 52 wheat and Pusa lentil Type 11, respectively. At harvest a substantial border was removed from all sides and the remaining field was sub-divided into 390 ultimate plots, each four feet square. The produce from these ultimate units was harvested and threshed separately. Combinations of $2 \times 3$ such ultimate plots were made for the purpose of drawing contour maps of the field based on the yields, the field consisting of 65 such combination plots, 5 plots running from west to east by 13 plots running north to south as shown in Fig. 1. Assuming that the average yield of each plot is located at the centre of a plot, the points at which the yields were 10, 20, 30, 40, etc., per cent above or below the mean yield of the crop were marked on the field plan. These points were joined and the contour maps shown in the figure given below were constructed.

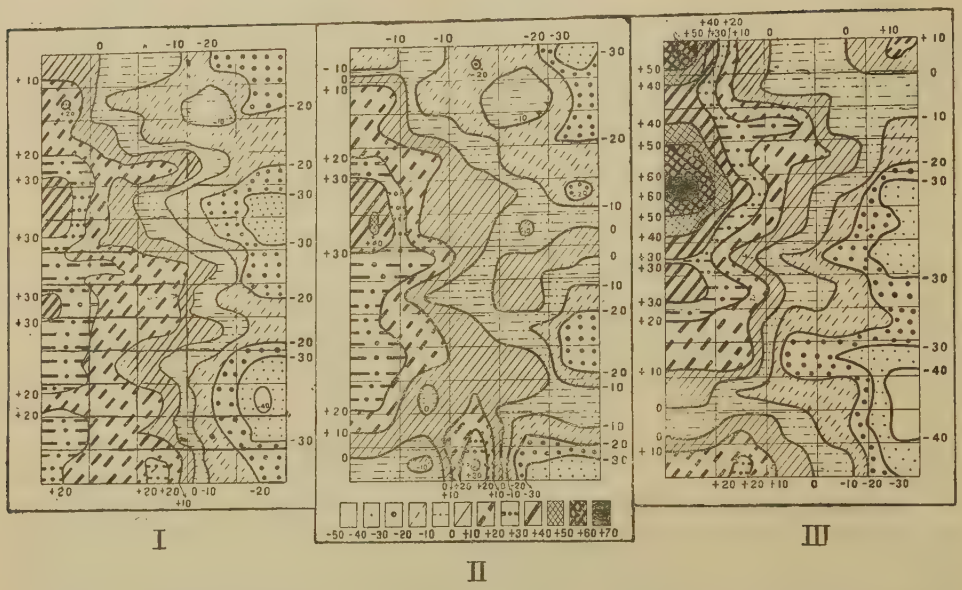


Fig. 1. Contour maps of the field based on yields of (*i*) barley, (*ii*) wheat and (*iii*) lentils, obtained in three successive years from the same experimental field.

It is evident that the yield varied greatly between different sub-plots in the same field, and that this heterogeneity was systematic to a considerable extent is also apparent as the fertility contour lines run, to a very pronounced degree, more or less parallel to the direction of the columns running north to south. The contour lines show a good deal of similarity in all the three maps shown above. The differences present are due, of course, to the variability in the yielding power of the different crops under consideration and its relation to the mean yield of the crop under the conditions of the experiment.

Generally speaking, soil-heterogeneity may exist either as a gradual change of productivity from one side of the field to the other, corresponding to the line of slope or the pathway of irrigation, etc., or as random patches of ground of higher or lower fertility. This 'patchiness' of a field is due to adjacent plots into which the field is divided resembling each other, and represents the most common type of soil heterogeneity. These irregularities in the field may be so powerful sometimes as to vitiate the results of varietal or breeding trials, giving significance to yields in situations where it is not actually present.

It must be remembered that the main object of the modern methods of field trials, and the application of refined methods of analysis to their results is to allow, as far as possible, for this effect of soil-heterogeneity. Although Fisher [1932] does not consider it necessary to crop the experimental plots in the year previous to the experiment, as it involves double the labour of the experiment and a year's delay

before the result is made available, it is profitable at times if the experimenter has some measure of the nature of his field and knows in which direction the soil-fertility varies the most. He has then the advantage of having valuable information to assist him in deciding on the layout of the experiment and on the correct size and shape of plots which he should choose. It is also possible for him then to discard fields of 'patchy' fertility for comparative trials. In agricultural experimental and demonstration stations where the testing of improved varieties of crops or their response to different manurial or other treatments forms an important item of work, a knowledge of the heterogeneity of different fields proves very advantageous indeed.

Harris [1915] has suggested that soil-heterogeneity may be measured by a coefficient which shows the degree of correlation between the yields of contiguous plots. Fisher's analysis of variance may also be employed to determine the drift in the fertility of the field. Whereas Harris' method provides a measure of heterogeneity present in the whole field, Fisher's analysis of variance method not only gives this measure but also clearly sets forth the direction of the fertility gradient and should, therefore, prove a more comprehensive method for such work. It is the purpose of this part of the paper to present the results of the heterogeinty tests conducted at Pusa and to give full arithmetical details of the methods of calculations that were employed.

## Historical

Mercer and Hall [1911] harvested 200 plots of mangolds, each 1/200th of an acre in size and 500 wheat plots, each 1/500th of an acre, and calculated the probable errors for combinations of different sizes and number of replications. They found that the experimental error diminished with the size of the plot but the reduction was small when the plots were above 1/40th of an acre. These authors reported that their mangolds 'looked a uniform and fairly heavy crop for the season and soil' while for their wheat 'a very uniform area was selected'. Harris used the same data for calculating the coefficient of correlation as a measure of soil-heterogeneity and found it to be—

*For mangolds for a 2×2 combination :—*

$r = +0{\cdot}346 \pm 0{\cdot}042$ (for roots)

$r = +0{\cdot}466 \pm 0{\cdot}037$ (for leaves)

*For wheat for a 4×5 combination :—*

$r = +0{\cdot}186 \pm 0{\cdot}029$ (for grain)

$r = +0{\cdot}343 \pm 0{\cdot}027$ (for straw)

Montgomery [1912] harvested 500 small plots of wheat separately from a field which was 'of about average uniformity and fertility' and tested the nitrogen content of the individual plots with a view to forming a basis of the heterogeneity

in the soil. Analysing this data Harris obtained a coefficient of correlation of $0 \cdot 603 \pm 0 \cdot 029$ for grain and $0 \cdot 115 \pm 0 \cdot 044$ for percentage of nitrogen for a $2 \times 2$ grouping. Lehmann [ 1901-1909 ] has given a series of data derived from the yields of grain and straw of *ragi* (*Eleusine coracana* Gaertn.) cultivated at the Hebbal Farm near Bangalore in India and these were analysed by Harris [ 1920 ] for correlation between the yield of grain, of straw, and of grain and straw. The following figures were obtained :—

| —— | 1905 | 1906 | 1907 |
|---|---|---|---|
| Grain . . . . . | $0 \cdot 735 \pm \cdot 031$ | $0 \cdot 138 \pm \cdot 065$ | $0 \cdot 716 \pm \cdot 032$ |
| Straw . . . . . | $0 \cdot 424 \pm \cdot 055$ | $0 \cdot 164 \pm \cdot 065$ | $0 \cdot 573 \pm \cdot 045$ |
| Total yield . . . . | $0 \cdot 415 \pm \cdot 055$ | $0 \cdot 145 \pm \cdot 065$ | $0 \cdot 636 \pm \cdot 040$ |

' The practical conclusion to be drawn from this result is that an experimental field which might be demonstrated to be sensibly uniform for one crop plant or for one season might not prove to be so for another crop or in a different season ' [ Harris, 1920 ].

Parnell [ 1919 ] in Madras determined the amount of soil variability in the typical paddy soils of the Presidency and found that they varied from 7·7 per cent to 13·9 per cent for the probable error of differences between two plots and for small plots, he came to the conclusion, based on a number of cases, that an area of $50 \times 4$ feet repeated 8 times would reduce the probable error of mean difference to about 2 per cent. At the Maruteru Paddy Breeding Station in Madras experiments of a preliminary type of the nature of " blank-tests " were conducted by Iliffe and Srinivasan [ 1926 ] to estimate the amount of error with a view to choosing the correct size and shape of plots. It was found that a 40 feet $\times$ 5 feet plot, replicated six times, reduced the probable error of difference to such an extent that a 10 per cent difference in the experiments would be significant.

Garber [ 1926 ] experimented with 270 plots of 68 feet $\times$ 2 feet for two years with wheat and oats and found that the coefficients of correlation for oats ranged rom $0 \cdot 542 \pm 0 \cdot 030$ to $0 \cdot 694 \pm 0 \cdot 031$ and for wheat from $0 \cdot 516 \pm 0 \cdot 031$ to $0 \cdot 617 \pm 0 \cdot 037$ and that there was some tendency for the plots which produced relatively high yields of oats to produce relatively high yields of wheat in the following year. There was also a correlation of $0 \cdot 364 \pm 0 \cdot 036$ between the yields of the same plots of the two crops in the two successive years.

Sanders [ 1930 ] has suggested the application of the analysis of covariance in order to increase the precision of experimental results on the basis of a knowledge of the yielding capacities of the same plots in a previous or preliminary trial. He tried to determine whether soil variations were sufficiently constant from year to

year to give useful corrections in the yields of experimental plots by considering the yields of the same plots under previous uniformity trials. Considering the published results of uniformity trials with cereals carried out on two fields at Aarslev (Denmark) during the years 1906 to 1911, he found that while in one field the precision of the experiment was increased by 150 per cent by utilising the previous records and correction of yields by the application of the method of covariance, yet in another field the plots showed no constancy in yield. Eden [1931], however, obtained results of increased precision with a perennial crop, tea, by correcting experimental yields on the basis of previous cropping.

## Material and method

An area measuring 0·24 acre, which was selected for running a yield trial experiment with some Pusa barleys in 1928-29 [Shaw and Bose, 1929], was chosen for conducting this trial. The soil consists of a sandy loam and no manure nor any irrigation was applied to this plot at any stage of the experiment. The following crops were grown :—

| | |
|---|---|
| Winter of 1927-28 . . . . | Lucerne. |
| ,, 1928-29 . . . . | Barley yield-trials [ Shaw and Bose 1929]. |
| ,, 1929-30 . . . . | Heterogeneity test with Pusa barley Type 21 [Bose, 1931]. |
| ,, 1930-31 . . . . | Heterogeneity test with wheat Pusa 52 [Howard, 1927] . |
| ,, 1931-32 . . . . | Heterogeneity trial with Pusa lentil Type 11 [Shaw and Bose, 1928]. |

All the crops used in this experiment were crops which are grown in India in the cold season from October to March. Sowing therefore took place about the end of October and harvest during the second half of March. During the period April to October each year the field was left fallow. Usual cultivation and weeding were given. For the heterogeneity or ' uniformity ' trials the crop was drilled in rows one foot apart, the usual* seed rate for the particular crop was always employed. At harvest borders of three feet each on the east and west and six feet each on the north and south of the field were removed and the remaining central area was divided into 390 equal-sized small plots, each four feet square. There were in all fifteen of these ultimate plots running east to west and 26 ultimate plots going north to south making in all 390 small plots (Fig. 2). The produce from each ultimate plot was threshed by hand and weighed separately. Care was taken to see that all weighings were done after the grain had been sun-dried for a number of days so as to obtain an approximately uniform moisture content.

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* Wheat 70 lb. per acre.
Barley 70 lb. per acre.
Lentils 16 lb. per acre.

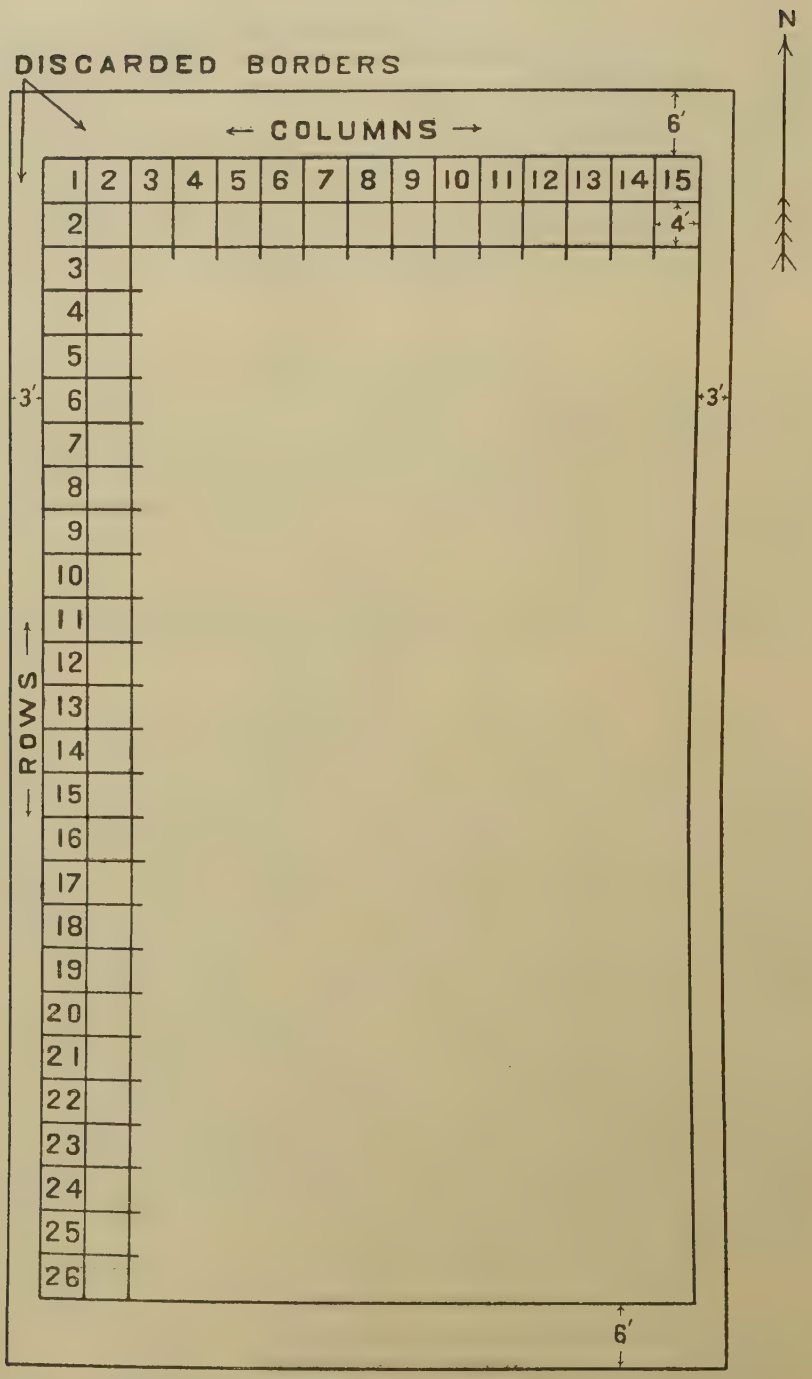


Fig. 2. Diagrammatic representation of the division of the experimental plot into ultimate units just before harvest.

Harris' method [ 1915 ] of estimating soil-heterogeneity based on the determination of the coefficient of correlation between the yielding powers of adjacent plots was employed in these studies and the results were further analysed by Fisher's analysis of variance which appears to be an excellent weapon for attacking such investigations.

## Experimental results

### (1) Harris' method

The yields of ultimate plots of barley obtained in 1929-30 are shown in Table I.

Table I

*Yield of barley Type 21 from ultimate plots 4 ft. × 4 ft. in area*

| Row No. | Yield in grms. from column No. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | 880 | 595 | 835 | 635 | 615 | 645 | 635 | 730 | 610 | 455 | 535 | 525 | 500 | 350 | 310 |
| 2 | 715 | 515 | 530 | 540 | 720 | 530 | 655 | 480 | 470 | 470 | 490 | 565 | 675 | 630 | 300 |
| 3 | 970 | 850 | 755 | 525 | 510 | 565 | 575 | 570 | 535 | 690 | 600 | 685 | 600 | 530 | 300 |
| 4 | 410 | 865 | 760 | 500 | 500 | 735 | 655 | 465 | 380 | 610 | 565 | 625 | 610 | 470 | 365 |
| 5 | 585 | 740 | 810 | 680 | 510 | 675 | 510 | 580 | 280 | 430 | 490 | 670 | 620 | 600 | 390 |
| 6 | 630 | 685 | 820 | 775 | 570 | 665 | 610 | 705 | 480 | 580 | 525 | 555 | 670 | 510 | 530 |
| 7 | 680 | 615 | 930 | 810 | 695 | 635 | 875 | 750 | 540 | 705 | 640 | 490 | 445 | 595 | 560 |
| 8 | 855 | 970 | 830 | 765 | 775 | 665 | 740 | 900 | 650 | 675 | 615 | 545 | 600 | 355 | 495 |
| 9 | 1010 | 635 | 890 | 830 | 585 | 545 | 500 | 615 | 630 | 510 | 475 | 520 | 540 | 420 | 300 |
| 10 | 890 | 810 | 935 | 745 | 675 | 615 | 495 | 720 | 525 | 495 | 540 | 300 | 595 | 430 | 265 |
| 11 | 805 | 635 | 850 | 755 | 625 | 525 | 485 | 795 | 470 | 320 | 570 | 460 | 500 | 490 | 315 |
| 12 | 1040 | 725 | 910 | 765 | 710 | 660 | 525 | 750 | 700 | 610 | 580 | 565 | 545 | 510 | 180 |
| 13 | 570 | 810 | 870 | 900 | 785 | 705 | 650 | 745 | 710 | 790 | 580 | 580 | 560 | 585 | 395 |
| 14 | 790 | 635 | 960 | 885 | 715 | 630 | 710 | 955 | 730 | 685 | 670 | 625 | 530 | 465 | 405 |
| 15 | 920 | 750 | 890 | 765 | 745 | 595 | 515 | 1030 | 785 | 670 | 440 | 375 | 450 | 500 | 505 |
| 16 | 895 | 770 | 870 | 720 | 840 | 720 | 780 | 805 | 650 | 610 | 610 | 800 | 555 | 500 | 585 |
| 17 | 810 | 775 | 800 | 625 | 865 | 785 | 770 | 630 | 630 | 785 | 705 | 565 | 610 | 660 | 490 |
| 18 | 935 | 675 | 830 | 750 | 635 | 760 | 790 | 720 | 700 | 790 | 525 | 605 | 690 | 360 | 460 |
| 19 | 900 | 720 | 870 | 725 | 625 | 665 | 465 | 660 | 690 | 670 | 620 | 570 | 650 | 310 | 335 |
| 20 | 755 | 600 | 930 | 695 | 815 | 690 | 785 | 650 | 535 | 430 | 460 | 470 | 420 | 435 | 305 |
| 21 | 670 | 720 | 800 | 670 | 760 | 750 | 610 | 610 | 650 | 415 | 630 | 545 | 425 | 450 | 315 |
| 22 | 780 | 700 | 810 | 790 | 810 | 705 | 820 | 850 | 675 | 590 | 550 | 350 | 370 | 360 | 230 |
| 23 | 885 | 740 | 960 | 690 | 755 | 680 | 630 | 635 | 850 | 590 | 490 | 755 | 550 | 480 | 365 |
| 24 | 940 | 680 | 700 | 825 | 665 | 650 | 615 | 700 | 675 | 460 | 450 | 410 | 420 | 355 | 390 |
| 25 | 880 | 575 | 630 | 610 | 625 | 695 | 850 | 775 | 730 | 425 | 380 | 605 | 650 | 375 | 280 |
| 26 | 955 | 765 | 850 | 810 | 725 | 710 | 920 | 730 | 710 | 680 | 600 | 660 | 710 | 420 | 515 |

Total sum of squares of all individual yields

$\Sigma p^2 = 166978025$

Mean of ultimate plots or $\bar{p} = \frac{247355}{390} = 634 \cdot 2436$

Two series of groupings hereafter called the $1\times5$ combination and the $2\times5$ combination respectively were made up by totalling together the yields of one plot north to south and five plots east to west in the first case, and two plots north to south and five plots east to west in the second case. Thus, out of 390 ultimate plots, 78 combination plots could be made up for $1\times5$ combination and 39 combination plots formed for the $2\times5$ combination. The yields of these two series of combination plots are shown in Tables II and III, respectively.

TABLE II

*Yield of barley in $1\times5$ combinaton plots*

| Row No. | Yield in grms. | | |
|---|---|---|---|
| | Block I | Block II | Block III |
| 1 | 3560 | 3075 | 2220 |
| 2 | 3020 | 2605 | 2660 |
| 3 | 3610 | 2935 | 2715 |
| 4 | 3035 | 2845 | 2635 |
| 5 | 3325 | 2475 | 2770 |
| 6 | 3480 | 3040 | 2790 |
| 7 | 3730 | 3505 | 2730 |
| 8 | 4195 | 3630 | 2610 |
| 9 | 3950 | 2800 | 2255 |
| 10 | 4055 | 2850 | 2130 |
| 11 | 3670 | 2595 | 2335 |
| 12 | 4150 | 3245 | 2380 |
| 13 | 3935 | 3600 | 2700 |
| 14 | 3985 | 3710 | 2695 |
| 15 | 4070 | 3595 | 2270 |
| 16 | 4095 | 3565 | 3050 |
| 17 | 3875 | 3600 | 3030 |
| 18 | 3825 | 3760 | 2640 |
| 19 | 3840 | 3150 | 2485 |
| 20 | 3795 | 3090 | 2090 |
| 21 | 3620 | 3035 | 2365 |
| 22 | 3890 | 3640 | 1910 |
| 23 | 4030 | 3385 | 2640 |
| 24 | 3810 | 3100 | 2025 |
| 25 | 3320 | 3475 | 2290 |
| 26 | 4105 | 3750 | 2905 |
| Total sum of squares | 371810375 | + 275598325 | + 166475925 |

*i.e.*, $\Sigma Cp^2 = 813884625$

TABLE III

*Yield of barley in 2×5 combination plots*

| Row No. | Yield in grms. | | |
|---|---|---|---|
| | Block I | Block II | Block III |
| 1 and 2 . . . | 6580 | 5680 | 4880 |
| 3 and 4 . . . | 6645 | 5780 | 5350 |
| 5 and 6 . . . | 6805 | 5515 | 5560 |
| 7 and 8 . . . | 7925 | 7135 | 5340 |
| 9 and 10 . . . | 8005 | 5650 | 4385 |
| 11 and 12 . . . | 7820 | 5840 | 4715 |
| 13 and 14 . . . | 7920 | 7310 | 5395 |
| 15 and 16 . . . | 8165 | 7160 | 5320 |
| 17 and 18 . . . | 7700 | 7360 | 5670 |
| 19 and 20 . . . | 7635 | 6240 | 4575 |
| 21 and 22 . . . | 7510 | 6675 | 4275 |
| 23 and 24 . . . | 7840 | 6485 | 4665 |
| 25 and 26 . . . | 7425 | 7225 | 5195 |
| Total sum of squares . | 741771675 + | 549642725 + | 330839375 |

*i.e.*, $\Sigma Cp^2 = 1622253775$

As already mentioned, the coefficient of correlation is used as an index of soil uniformity as advanced by Harris [ 1915 ]. This constant usually termed $r_{p_1p_2}$ is calculated according to the following formula :—

$$r_{p_1p_2} = \frac{[\{\Sigma(Cp^2) - \Sigma(p^2)\}/m\{n(n-1)\}] - \bar{p}^2}{\sigma p^2}$$

where

$r_{p_1p_2}$ = the coefficient of correlation sought.

$\Sigma(Cp^2)$ = sum of squares of group yields of combination plots.

$\Sigma(p^2)$ = sum of squares of the yields of ultimate units.

$\bar{p}^2$ = square of the average yield of all ultimate units.

$n$ = number of units in each group.

$m$ = number of groups of combination plots.

$\sigma p$ = square of the standard deviation of yield for the ultimate units.

The squares of all yields, *i.e.*, of ultimate plots or of combination plots are written down and summated, and the standard deviation of yields for the ultimate units is obtained by the formula—

$$\sigma p = \sqrt{\frac{\Sigma(p^2)}{mn} - (\bar{p})^2}$$

where as stated above $\Sigma(p^2)$ is the sum of squares of the yields of the ultimate units and $\bar{p}$ is the average yield of all ultimate units. By substituting the actual values obtained for the barley experiment we get—

*For the 1×5 combination*

$$r_{p_1p_2} = \frac{[\{813884625-166978025\}/78\{5(5-1)\}]-(634\cdot2436)^2}{\left\{\sqrt{\frac{166978025}{390}-\left(\frac{247355}{390}\right)^2}\right\}^2}$$

$$= \frac{\{646906600/1560\} - 402264\cdot9441}{\{\sqrt{428148\cdot7820-402264\cdot9441}^2}$$

$$= \frac{414683\cdot7179-402264\cdot9441}{25883\cdot8379} = 0\cdot4798$$

$$\text{Standard error} = \pm\frac{(1-r^2)}{\sqrt{n}} = \pm 0\cdot0390$$

$$\therefore r_{p_1p_2} = 0\cdot4798 \pm 0\cdot0390$$

*For the 2×5 combination*

$$r_{p_1p_2} = \frac{[\{1622253775-166978025\}/\ 39\{10(10-1)\}] - (634\cdot2436)^2}{\left\{\sqrt{\frac{166978025}{390}-\left(\frac{247355}{390}\right)^2}\right\}^2}$$

$$= \frac{\{1455275750/3510\}-402264\cdot9441}{25883\cdot8379}$$

$$= \frac{414608\cdot4758-402264\cdot9441}{25883\cdot8379} = 0\cdot4769$$

$$\text{Standard error} = \pm\frac{(1-r^2)}{\sqrt{n}} = \pm 0\cdot0391$$

$$\therefore r_{p_1p_2} = 0\cdot4769 \pm 0\cdot0391$$

It may be pointed out that the large figures in these calculations have been obtained only because yields were retained in units of grammes. A calculating machine, the ' Comptometer ' having been used, no difficulty whatsoever was experienced in handling these figures. The yields could have been converted into decagrammes or even kilogrammes and the size of figures for their respective squares could thus have been reduced.

*Wheat, 1930-31*

In the following year Pusa 52 wheat was similarly sown in this very area and Table IV given below shows the yield of ultimate plots.

TABLE IV

*Yield of Pusa 52 wheat from ultimate plots 4 ft. × 4 ft. in area*

| Row No. | Yield in grms. from column No. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | 70 | 220 | 265 | 230 | 248 | 322 | 205 | 250 | 180 | 225 | 235 | 280 | 155 | 190 | 120 |
| 2 | 248 | 258 | 215 | 220 | 200 | 185 | 185 | 258 | 120 | 215 | 145 | 190 | 210 | 180 | 120 |
| 3 | 275 | 402 | 225 | 120 | 275 | 195 | 200 | 220 | 217 | 185 | 335 | 250 | 235 | 190 | 170 |
| 4 | 270 | 400 | 385 | 240 | 225 | 200 | 200 | 252 | 255 | 268 | 235 | 220 | 300 | 130 | 170 |
| 5 | 195 | 230 | 335 | 272 | 200 | 210 | 190 | 340 | 205 | 222 | 295 | 160 | 230 | 235 | 155 |
| 6 | 240 | 348 | 335 | 296 | 185 | 250 | 185 | 235 | 160 | 170 | 225 | 235 | 250 | 132 | 140 |
| 7 | 275 | 280 | 325 | 390 | 200 | 215 | 210 | 175 | 212 | 142 | 270 | 240 | 220 | 120 | 270 |
| 8 | 218 | 335 | 400 | 370 | 235 | 340 | 260 | 310 | 305 | 160 | 200 | 200 | 335 | 232 | 100 |
| 9 | 260 | 415 | 430 | 365 | 230 | 220 | 245 | 370 | 232 | 232 | 222 | 215 | 235 | 150 | 130 |
| 10 | 275 | 375 | 360 | 340 | 240 | 250 | 160 | 375 | 257 | 232 | 340 | 260 | 260 | 190 | 210 |
| 11 | 335 | 392 | 305 | 300 | 200 | 232 | 225 | 345 | 210 | 280 | 180 | 185 | 310 | 280 | 245 |
| 12 | 345 | 380 | 360 | 320 | 265 | 255 | 220 | 420 | 200 | 155 | 250 | 255 | 235 | 260 | 200 |
| 13 | 270 | 310 | 415 | 385 | 250 | 262 | 230 | 290 | 190 | 280 | 320 | 220 | 290 | 160 | 240 |
| 14 | 155 | 395 | 355 | 398 | 330 | 265 | 255 | 350 | 172 | 260 | 328 | 190 | 280 | 255 | 295 |
| 15 | 295 | 318 | 305 | 408 | 215 | 247 | 235 | 400 | 182 | 280 | 315 | 245 | 345 | 140 | 250 |
| 16 | 335 | 185 | 422 | 190 | 220 | 210 | 155 | 335 | 130 | 265 | 245 | 300 | 208 | 140 | 220 |
| 17 | 242 | 280 | 295 | 305 | 225 | 210 | 295 | 345 | 132 | 258 | 215 | 132 | 130 | 135 | 205 |
| 18 | 305 | 310 | 400 | 312 | 450 | 210 | 305 | 290 | 182 | 342 | 275 | 145 | 210 | 180 | 255 |
| 19 | 380 | 250 | 320 | 322 | 300 | 327 | 232 | 290 | 320 | 305 | 260 | 165 | 140 | 140 | 190 |
| 20 | 318 | 367 | 355 | 225 | 348 | 232 | 230 | 320 | 150 | 345 | 290 | 265 | 265 | 160 | 130 |
| 21 | 347 | 412 | 280 | 300 | 290 | 205 | 287 | 315 | 185 | 355 | 220 | 240 | 280 | 180 | 295 |
| 22 | 260 | 308 | 305 | 230 | 230 | 205 | 315 | 385 | 185 | 225 | 257 | 222 | 237 | 200 | 230 |
| 23 | 264 | 308 | 280 | 270 | 310 | 235 | 265 | 380 | 285 | 227 | 235 | 200 | 267 | 165 | 250 |
| 24 | 248 | 318 | 280 | 270 | 205 | 275 | 320 | 328 | 245 | 192 | 180 | 200 | 235 | 185 | 240 |
| 25 | 210 | 315 | 265 | 260 | 155 | 200 | 415 | 370 | 255 | 170 | 150 | 190 | 245 | 245 | 115 |
| 26 | 230 | 302 | 180 | 270 | 170 | 200 | 335 | 312 | 315 | 260 | 100 | 187 | 155 | 150 | 82 |

Total sum of squares of all individual yields

$$\Sigma p^2 = 26741531$$

Mean of ultimate plots or $\bar{p} = \frac{98217}{390} = 251 \cdot 838$ grms.

*Lentils, 1931-32*

Similarly in Table V the yield of lentils from ultimate plots obtained from this very field in the following year are shown.

TABLE V

*Yield of lentil Type 11 from ultimate plots 4 ft. × 4 ft. in area*

| Row No. | Yield in grms. from column No. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | 412 | 381 | 312 | 182 | 272 | 231 | 255 | 217 | 254 | 166 | 259 | 272 | 188 | 249 | 179 |
| 2 | 325 | 329 | 265 | 229 | 214 | 178 | 147 | 149 | 178 | 208 | 164 | 205 | 291 | 251 | 278 |
| 3 | 312 | 300 | 311 | 253 | 234 | 168 | 152 | 208 | 224 | 222 | 181 | 219 | 197 | 176 | 241 |
| 4 | 288 | 305 | 235 | 276 | 218 | 185 | 259 | 191 | 180 | 140 | 252 | 221 | 148 | 207 | 220 |
| 5 | 273 | 306 | 272 | 306 | 232 | 217 | 286 | 177 | 148 | 161 | 204 | 228 | 189 | 205 | 184 |
| 6 | 332 | 337 | 310 | 283 | 280 | 265 | 220 | 279 | 216 | 235 | 174 | 178 | 177 | 187 | 220 |
| 7 | 431 | 333 | 304 | 328 | 265 | 201 | 249 | 252 | 251 | 250 | 206 | 240 | 186 | 203 | 181 |
| 8 | 342 | 331 | 313 | 351 | 204 | 218 | 265 | 267 | 174 | 230 | 240 | 140 | 143 | 171 | 189 |
| 9 | 401 | 315 | 317 | 344 | 259 | 267 | 279 | 227 | 277 | 203 | 241 | 165 | 126 | 149 | 124 |
| 10 | 394 | 352 | 325 | 338 | 311 | 233 | 268 | 181 | 133 | 178 | 177 | 202 | 158 | 155 | 129 |
| 11 | 275 | 357 | 300 | 261 | 275 | 271 | 285 | 175 | 176 | 165 | 207 | 163 | 160 | 161 | 135 |
| 12 | 338 | 299 | 334 | 289 | 218 | 249 | 310 | 163 | 263 | 215 | 181 | 143 | 159 | 125 | 171 |
| 13 | 285 | 279 | 266 | 257 | 200 | 200 | 266 | 162 | 220 | 188 | 186 | 160 | 109 | 122 | 155 |
| 14 | 306 | 269 | 272 | 253 | 178 | 252 | 224 | 81 | 169 | 211 | 108 | 127 | 184 | 109 | 139 |
| 15 | 253 | 260 | 312 | 284 | 265 | 282 | 290 | 143 | 161 | 159 | 179 | 180 | 211 | 160 | 130 |
| 16 | 276 | 319 | 331 | 232 | 278 | 243 | 239 | 194 | 220 | 253 | 192 | 185 | 126 | 138 | 177 |
| 17 | 235 | 255 | 266 | 268 | 276 | 217 | 203 | 131 | 181 | 180 | 210 | 140 | 198 | 164 | 164 |
| 18 | 252 | 260 | 235 | 259 | 203 | 229 | 236 | 137 | 173 | 194 | 109 | 266 | 220 | 122 | 161 |
| 19 | 305 | 230 | 182 | 234 | 237 | 248 | 190 | 128 | 126 | 148 | 173 | 134 | 216 | 105 | 143 |
| 20 | 226 | 240 | 259 | 305 | 272 | 212 | 193 | 143 | 141 | 173 | 142 | 125 | 135 | 96 | 97 |
| 21 | 307 | 255 | 186 | 197 | 221 | 205 | 166 | 259 | 170 | 185 | 170 | 197 | 134 | 109 | 146 |
| 22 | 252 | 202 | 170 | 163 | 160 | 176 | 211 | 122 | 160 | 259 | 149 | 193 | 107 | 99 | 115 |
| 23 | 226 | 172 | 168 | 251 | 250 | 224 | 244 | 224 | 167 | 184 | 122 | 120 | 136 | 126 | 131 |
| 24 | 261 | 147 | 195 | 211 | 262 | 200 | 210 | 165 | 237 | 193 | 219 | 178 | 135 | 106 | 101 |
| 25 | 282 | 168 | 208 | 259 | 295 | 270 | 229 | 216 | 202 | 225 | 200 | 175 | 126 | 95 | 99 |
| 26 | 243 | 165 | 250 | 227 | 255 | 259 | 253 | 239 | 209 | 220 | 183 | 176 | 156 | 162 | 208 |

Total sum of squares of all individual yields

$$\Sigma p^2 = 19714274$$

Mean of ultimate plots $\bar{p} = \frac{84128}{390} = 215 \cdot 713.$

The following table shows the coefficients of correlation obtained with the three different crops under trial in three different seasons :—

TABLE VI

*Correlations for soil heterogeneity based upon the yields obtained from 390 ultimate plots, each 4 ft. square*

| Crop | Year | Coefficient of correlation ($r_{p_1 p_2}$) | | Differences between the two coefficients of correlation and standard error |
|---|---|---|---|---|
| | | 1 × 5 combination | 2 × 5 combination | |
| Barley Type 21 | 1929-30 | 0·4798 ± 0·0390 | 0·4769 ± 0·0391 | 0·0029 ± 0·0552 |
| Wheat Pusa 52 | 1930-31 | 0·2361 ± 0·0468 | 0·2504 ± 0·0506 | 0·0143 ± 0·0689 |
| Lentil Type 11 | 1931-32 | 0·5830 ± 0·0333 | 0·5921 ± 0·0329 | 0·0091 ± 0·0468 |

DISCUSSION OF RESULTS

Harris [1920] has pointed out that an exact measure of the influence of soil-heterogeneity is the first and most fundamental step in the closer analysis of the factors determining the variability of plot yields. If the application of such a criterion to results of uniformity trials shows no evidence of heterogeneity, plot tests may be carried out along conventional lines with confidence, and with reasonable precautions reliable results will be obtained. If, on the other hand, the application of such a criterion shows a high degree of irregularity in fields selected for their uniformity, it is evident that very special precautions must be taken to obtain trustworthy results. For a criterion of field heterogeneity Harris [1915] has suggested the coefficient of correlation of yields of contiguous plots. He believes that if a field sown with a single crop variety be divided into $n$ small plots and if $p$ denotes the yield of an individual plot, then the variability of $p$ may be due purely and simply to chance, since the individuals of any variety are variable and the size of plots is small, or it may be due in part to the diversity of conditions of the soil. If the irregularities of the field are so large as to influence the yield of areas larger than single plots, they will tend to bring about a similarity of adjoining plots, some groups of plots tending to yield higher than the average, others lower. As heterogeneity becomes greater the correlation will also increase. The value of the coefficient obtained will depend somewhat upon the nature of the characters measured, the species grown, the size of the ultimate and combination plots, and to some degree upon the form of the combination plots.

In our experiments it should be noted that $n$ was equal to 390 ultimate plots, each of these plots being four feet square. The combination plots in $1\times5$-fold grouping were therefore 4 ft.$\times$ 20 ft. in area and 78 in number ; while those in the $2\times5$-fold grouping were 8 ft.$\times$20 ft. in area and 39 in number.

The results shown in Table VI are of interest as they again bring out the fact that an experimental field which may be sensibly uniform for one crop or for one season may not be so for another crop or in a different season.

Whereas the coefficient of correlation for Pusa 52 wheat in 1930-31 is not very high for both the $1\times$ 5 and the $2\times5$-fold groupings, the coefficients are quite high in the case of barley in 1929-30 and lentils in 1931-32. Moreover, the coefficients of correlation in the two different kinds of grouping, in all the three crops under consideration, do not seem to be significantly different from one another, as is seen in the last column, where the differences of the two coefficients are in every case less than their respective standard errors. The coefficients of correlation in all cases appear to be significant when compared with their respective standard errors. The heterogeneous nature of the plot is therefore evident and the data will now be examined to see in what manner the soil-fertility varies in this field.

The means, standard deviations and the coefficients of variation obtained in these experiments and the standard errors of these constants are set forth in the table given below. These constants have been obtained by working with degrees of freedom equal to $n$—1 to keep the calculations in conformity with that followed in determining the constants for the heterogeneity coefficient. In this respect, as in others, Harris' method has been followed.

TABLE VII

*Means, standard deviations, and coefficients of variation for the yields of barley, wheat and lentils*

| Crop | Year | Mean yields in grms. | Standard deviation | Coefficient of variation |
|---|---|---|---|---|
| Barley Type 21 | 1930 | 634·244±8·166 | 161·286±5·775 | 25·429±0·968 |
| Wheat Pusa 52 | 1931 | 251·838±3·730 | 73·691±2·637 | 29·261±1·136 |
| Lentil Type 11 | 1932 | 215·713±3·217 | 63·538±2·274 | 29·455±1·143 |

The means in this table show that the yields vary with the crop, the standard deviations naturally are influenced by the actual magnitudes of the yields and are therefore difficult of interpretation, whereas the coefficients of variation are more or less uniform. This suggests that the coefficient of variability is a more

reliable index than the mean and the standard deviation for judging the variability of a sample. In comparing "variations" under different sets of conditions or factors (as in dealing with different crops), therefore, the coefficient of variation is the most satisfactory index.

## (2) Analysis of variance

### *The Latin square*

All modern methods of field-experimentation have for their object the elimination of the factor of soil-heterogeneity. Of the more modern methods, Fisher's analysis of variance can be employed as an efficient tool for determining the 'drift' in the fertility of a given area. The plot yields obtained in the experiment under report have therefore also been analysed by applying this method. For the sake of convenience yields from the 26th row have been discarded and the whole area has been grouped into a $5 \times 5$ Latin square. Each individual plot of this Latin square therefore consists of fifteen ultimate plots, three running west to east by five lying north to south. The yields of these plots are shown in Table VIII.

## Table VIII

*Yields in decagrammes in grouped plots of barley, wheat and lentils*

| BARLEY TYPE 21 | | | | |
|---|---|---|---|---|
| 1081·5 | 888·5 | 813·0 | 840·5 | 725·0 |
| 1218·5 | 1035·0 | 973·5 | 817·0 | 731·0 |
| 1216·0 | 1076·5 | 1055·5 | 825·0 | 693·5 |
| 1213·5 | 1091·5 | 1026·0 | 921·5 | 736·5 |
| 1147·0 | 1068·0 | 1067·5 | 764·5 | 606·5 |

| WHEAT PUSA 52 | | | | |
|---|---|---|---|---|
| 399·5 | 334·2 | 327·7 | 346·0 | 279·0 |
| 487·1 | 412·6 | 369·1 | 334·3 | 297·4 |
| 493·5 | 433·2 | 392·4 | 374·3 | 378·5 |
| 476·4 | 408·6 | 371·1 | 380·7 | 280·8 |
| 440·0 | 364·0 | 453·5 | 326·3 | 336·9 |

| LENTIL TYPE 11 | | | | |
|---|---|---|---|---|
| 462·6 | 339·5 | 302·5 | 310·2 | 320·3 |
| 513·7 | 414·7 | 353·8 | 305·9 | 249·8 |
| 440·5 | 373·4 | 308·8 | 257·2 | 223·0 |
| 387·1 | 371·3 | 263·5 | 262·4 | 226·2 |
| 319·9 | 334·4 | 298·2 | 276·9 | 176·5 |

The full arithmetical details of calculating the analysis of variance of these trials have not been given as such details are available in Fisher and Wishart [1930], Mahalanobis [1932] and Bose [1932] as well as in many other recent publications on the subject. The final analyses of variance are brought out in Table IX.

## Table IX

*Analyses of variance*

| Due to | Degrees of freedom | Sum of squares | | | Mean squares | | | $\frac{1}{2}\log_e$ Mean square | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Barley | Wheat | Lentil | Barley | Wheat | Lentil | Barley | Wheat | Lentil |
| Columns . . | 4 | 677558·00 | 57270·86 | 106223·44 | 169389·50 | 14317·71 | 26555·86 | 6·02001 | 4·78456 | 5·09341 |
| Rows . . . | 4 | 47814·30 | 15199·33 | 23801·82 | 11953·57 | 3799·83 | 5950·46 | 4·69442 | 4·12126 | 4·34558 |
| Error . . . | 16 | 61926·20 | 15586·88 | 19967·75 | 3870·39 | 974·18 | 1247·98 | 3·90027 | 3·44079 | 3·09614 |
| Total . . . | 24 | 787298·50 | 88057·07 | 149993·01 | ... | ... | ... | ... | ... | ... |
| Standard error . | ... | ... | ... | ... | 62·212 | 31·21 | 35·327 | ... | ... | ... |

From the analyses of variance given above it will be noted that the differences of mean squares between columns and error are much greater than the differences of mean squares between rows and error. Applying Fisher's $z$-test for the one and five per cent levels of significance, we get the results shown in the following table :—

TABLE X

*Differences between the $\frac{1}{2}\log_e$ (Mean square values) and their statistical significance*

| Crop | Values of $z$ between | | |
|---|---|---|---|
| | Row and error $n_1=4$ and $n_2=16$ | Column and error $n_1=4$ and $n_2=16$ | Column and row $n_1=4$ and $n_2=4$ |
| Barley . . | 0·79415 Significant at one per cent. | 2·11974 Significant at one per cent. | 1·32559 Not significant at one per cent but significant at 5 per cent. |
| Wheat . . | 0·68047 Not significant at one per cent but significant at 5 per cent. | 1·34377 Significant at one per cent. | 0·66330 Not significant. |
| Lentil . . | 0·78103 Not significant at one per cent but significant at 5 per cent. | 1·52886 Significant at one per cent. | 0·74783 Not significant. |

From Fisher's table $z=0\cdot7814$ for $P=0\cdot01$ and $0\cdot5505$ for $P=0\cdot05$ when $n_1=4$ and $n_2=16$ and $z=1\cdot3856$ for $P=0\cdot01$ and $0\cdot9272$ for $P=0\cdot05$ when $n_1=4$ and $n_2=4$.

When the rows or columns are to be compared with error in the above table a difference greater than $0\cdot7814$ for $n_1=4$ and $n_2=16$ is statistically significant. On the other hand if the rows and columns are to be compared with each other a difference greater than $1\cdot3856$ for $n_1=4$ and $n_2=4$ is significant at the one per cent level. The results show a comparatively greater difference in fertility between the columns than between the rows. In this field, therefore, there is a fertility gradient from west to east running at right angles to the direction of the columns.

It may be pointed out that the analysis of variance method has been utilized in this case mainly to show the differences in soil-fertility and to show that a greater precision can be obtained in the standard error of the experiment by eliminating the variances due to soil-fertility.

Increased precision in the standard error may further be obtained in experiments such as these, where the same field or parts of the same field are employed

for two or more seasons in succession by utilizing Fisher's method of covariance for correcting the standard error of the experiment in the second or third year on the basis of that obtained in the first year.

The details of calculation for the reduction of the experimental error in the case of the present barley and wheat trials by the application of the covariance method have been provided in example 24 of Shaw's Handbook of Statistics for use in Plant Breeding and Agricultural Problems (*in Press*) and need not be repeated here. It is evident, however, that by taking preliminary yields into consideration increased precision to some extent may be obtained in the experimental error of the successive crop. Thus the mean square for error for Pusa 52 wheat is 974·18 as shown in Table IX and this could be reduced to 860·88 if the preliminary yields of barley in the same sub-plots are taken into consideration and the analysis of covariance is applied to this test. The precision of the comparison has thus been increased by $\frac{974 \cdot 18}{860 \cdot 88}$ or 1·13 times. Similarly, in the lentil trial, an improvement of 1·04 times can be effected in the standard error by applying the method of covariance. But as this hardly affects our results, we have not utilized these improved standard errors in our present study.

If we consider the yields of lentils obtained in the third year of the present experiment, we find that the yields range from 3952 grms. to 7832 grms. in the direction of the columns showing a coefficient of variability of approximately 21 per cent. The yields in the direction of the rows, on the other hand, range from 2638 grms. to 3880 grms. and have a coefficient of variation of only 11 per cent. Fig. 3 depicts these yields plotted out and their relation to the respective means of the total yields of columns and those of the rows. This shows again that there is a greater variation in the yields between columns than those between rows.

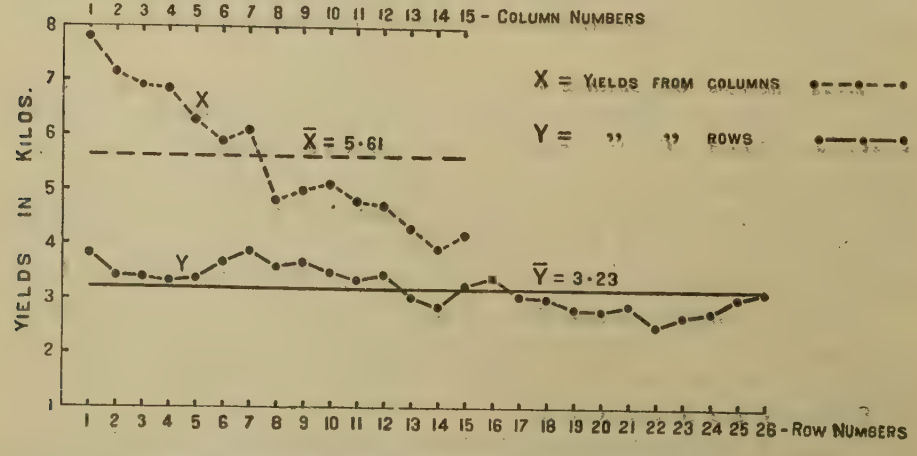


Fig. 3. Variation in yields of lentils from columns and rows.

## Conclusions

A soil-heterogeneity experiment was conducted in a particular field for three consecutive years with barley, wheat and lentils respectively. After discarding the necessary borders the field was divided at harvest into 26 × 15 or 390 ultimate plots, each 4 feet square. The produce of each ultimate plot was separately harvested, hand-threshed and sun-dried. Weights were taken in grammes.

The coefficient of correlation between contiguous plots was employed as an index of soil-heterogeneity according to the method advocated by Harris. 1 × 5 and 2 × 5 combination plots were made up for this purpose by summing up the yields of either 5 or 10 contiguous plots ; so that the 390 ultimate plots could be formed into 78 combination plots with the 1 × 5 grouping and 39 combination plots with the 2 × 5 grouping.

The coefficients of correlation for the two kinds of combinations are not significantly different from one another. For the different crops tried in three different years this constant was as follows :—

| Crop | Year | Coefficients of correlation | |
|---|---|---|---|
| | | 1 × 5 combination | 2 × 5 combination |
| Barley . . . | 1929-30 . . | 0·4798 ± 0·0390 | 0·4769 ± 0·0391 |
| Wheat . . . | 1930-31 . . | 0·2361 ± 0·0468 | 0·2504 ± 0·0506 |
| Lentils . . . | 1931-32 . . | 0·5830 ± 0·0333 | 0·5921 ± 0·0329 |

This shows clearly that an experimental field which is sensibly uniform for one crop in one season may not be so for another crop or in a different season, a result which is in conformity with those obtained by Harris in 1920. The presence of high correlation between contiguous plots signifies that, notwithstanding its uniform cultural and other treatments, the field has definite grades of fertility, which are so large as to influence the yields of areas larger than single combination plots in the field ; thus bringing about a similarity of adjoining plots, some groups tending to yield higher than the average, others lower.

Combinations of 2 × 3 ultimate plots were made and the field was considered as consisting of 65 such combination plots. Assuming the average yield of each plot to be at the centre, the points at which the yields were 10, 20, 30, 40, etc., per cent above or below the mean yield were found by interpolation between adjacent plots. These points were joined and the contour maps shown on page 580 were constructed. It is evident that the yield varied greatly between different

plots in the same field. That this heterogeneity was systematic to a considerable extent is also apparent as the fertility contour lines run more or less parallel to the columns (north to south) to a very pronounced degree [Bose, 1933]. The contour lines show a good deal of similarity in all the three maps shown above. The differences are due, of course, to the variability in the yielding power of the different crops under consideration and their relation to the mean yields of each.

It has also been found that, although the mean yields in this field have varied widely with the crop, the coefficients of variation have remained more or less uniform in the three years under report. Barley, for instance, gave a mean yield of about 634 grms. per ultimate plot, wheat has given only about 251 grms., and lentils about 216 grms. The coefficients of variability in these crops were 25·4, 29·3, and 29·4 per cent, respectively.

Fisher's analysis of variance method is one of the best tools for determining the drift in the fertility of a given area. The plot yields obtained in these experiments were therefore analyzed by applying this method also. Discarding the yields of the last or the 26th row, it is possible to compose a $5 \times 5$ Latin square with the yields of the remaining ultimate plots. On analysis it is found that there is a statistically significant difference between the variance for ' columns ' and that for ' error ' and also between the variance for ' rows ' and ' error '. From this it may be inferred that fertility gradients run both along rows and along columns.

It may be pointed out that Harris' method of determining soil-heterogeneity by the estimation of the coefficient of correlation between contiguous plots provides a measure for heterogeneity present in the whole field. On the other hand, Fisher's analysis of variance method which has come into existence long after Harris' method, not only provides a measure of soil-heterogeneity but also clearly sets forth the direction of the fertility slope. The latter method should, therefore, furnish a more comprehensive estimate of variations in fertility in different parts of a field.

In agricultural experimental stations where the testing of improved varieties of crops or their response to different manurial treatments forms an important item of work, a knowledge of the uniformity of different fields proves very advantageous in the guidance that it usually gives in designing future lay-outs on such fields. All that is required in this connection is that each year one or two fields which are under any bulk crop in the station may be harvested in the form of small ultimate units of convenient size and shape. The yields of these ultimate plots will furnish sufficient evidence to determine the nature of the heterogeneity of the field and also of the direction of the fertility gradient present therein. From this study the correct size and shape of plots that would furnish reliable results can also be determined. The threshing of these separate small units would undoubtedly entail some extra expenditure, but this would be amply compensated for by obtaining a reliable index of the nature of the field for further trials.

Statistical methods, it must be remembered, furnish trustworthy results only if they are employed in the right way to properly controlled field experiments [Bose, 1933]. If an experiment is wrongly placed no method can be expected to give significant results.

## II. THE SIZE AND SHAPE OF EXPERIMENTAL PLOTS

The existence of soil-heterogeneity in an experimental plot at Pusa has been shown in the first part of this paper and it has been pointed out that one of the chief advantages of estimating soil-heterogeneity in experimental fields is that this furnishes material on which to base the proper lay-out and to determine the correct size and shape of plots necessary to reduce errors due to soil-fertility, etc., to a minimum. Should the yields of ultimate units in a field be known, it is possible to combine these in various ways so as to get lay-outs with different plot sizes and plot shapes and the one which shows the least standard error may be gauged to be the best for the conditions of the experiment. Fisher's analysis of variance may be used for determining the standard errors of the various combinations. The results obtained in the wheat trial reported in the preceding pages may be employed to furnish some idea of the actual arithmetical details necessary.

Studies to determine the most efficient size and shape of plot have been conducted with a great variety of crops and under different sets of conditions. Even then there is a great scope for this kind of work under varied conditions of soils and climate that obtain in India. In their classical experiments, Mercer and Hall [1911] calculated the probable errors for combinations of different sizes and number of replications of small unit plots, each 1/500 of an acre in area, and found that the error diminished with the size of the plot, but that the reduction was small when the plots grew above 1/40th of an acre. Parnell [1919] found that an area of 50 $\times$ 4 feet repeated eight times would reduce the probable error of mean difference in paddy to about two per cent. Iliffe and Srinivasan [1926] observed that a 40 $\times$ 5 feet plot replicated six times reduced the probable error of the difference in paddy to such an extent that a 10 per cent difference in the experiments would be significant.

Immer [1932] studied the size and shape of plots in relation to field-experiments with sugar-beets and found that the standard errors, expressed as percentages of the mean, decreased in general with increased size of plot, and that the experimental efficiency of the land decreased with increased size of plot when the entire plot was harvested. When the border rows of the plots were removed 4-row plots were most efficient.

A complete bibliography bearing on this subject has been published by a committee of the American Society of Agronomy for the standardization of field-experiments in the *Journal of the American Society of Agronomy*, **18**, 1926, pages 1143—1144 ; **22**, 1930, pages 1056—1061.

In plant-breeding work, where numerous strains are compared, the size and shape of plot is necessarily limited by available space and sometimes by the amount of seed. In comparative yield trials, however, where only a few varieties are being compared, it is always possible to lay out plots of such size and shape as will reduce the errors due to variation in soil-fertility to a minimum. This is easily accomplished if an idea of soil-heterogeneity in the experimental field under observation is available.

The data obtained from the uniformity trial with Pusa 52 wheat has been employed for the purpose of determining the best size and shape of plot which could be oriented in this particular field for future experiments and which would reduce the experimental error to its minimum. In Table IV have been presented the yields of 26 × 15 ultimate plots of Pusa 52 wheat, but for the sake of convenience the ultimate plots in the last two rows have been omitted for the present study and the yields of 24 × 15 or 360 ultimate units only have been taken into consideration. By combining plot yields of various numbers of adjacent ultimate units combination blocks of different sizes and shapes can be formed. Fisher's analysis of variance may be used and five hypothetical treatments may be assumed in order to make due allowance for soil-heterogeneity. Thus, in each combination or lay-out the total variance is split up into variance due to (1) 'between blocks' and (2) 'within blocks'. The variance due to the last item gives as its square root the standard deviation of the combination plots from which the coefficient of variation can be computed.

Taking the 3 × 3 combination as an illustration, we find that the experimental field could be divided into 40 sub-plots, each 12 ft. × 12 ft. in size, and in which the yields of three ultimate units in the direction of the rows and of three units in the direction of the columns have been combined to represent the yield of each sub-plot. On the assumption of five hypothetical treatments we can thus divide the field into 40/5 or 8 blocks. The plot yields of this lay-out are shown on the margin. The total sum of squares for calculating the analysis of variance is obtained by squaring the yield of each sub-plot, summing and subtracting from this the correction factor which is obtained by dividing the square of the general total by the total number of combination plots—in this case 40.

| Block | | | | | | Block total |
|---|---|---|---|---|---|---|
| I | 2178 | 1995 | 1835 | 2060 | 1570 | 9638 |
| II | 2738 | 2078 | 2022 | 2030 | 1742 | 10610 |
| III | 2938 | 2568 | 2319 | 1881 | 1792 | 11495 |
| IV | 3127 | 2402 | 2412 | 2137 | 2190 | 12268 |
| V | 2818 | 2760 | 2304 | 2438 | 2255 | 12575 |
| VI | 2774 | 2332 | 2169 | 2177 | 1683 | 11135 |
| VII | 3029 | 2549 | 2329 | 2445 | 1880 | 12232 |
| VIII | 2571 | 2230 | 2708 | 1938 | 2009 | 11456 |
| | | | | | General total | 91409 |

$$\text{Correction factor} = \frac{(91409)^2}{40} = 208890132{\cdot}025$$

*Plot and block yields in 3 × 3 combination.*

The sum of squares ' between blocks ' is computed by squaring the block yields, summing these up and dividing this sum by the number of blocks, and finally, subtracting the same correction factor as was used in obtaining the true total sum of squares. The sum of squares due to variations ' within blocks ' is therefore the difference between the total sum of squares and that due to variations ' between blocks '. The analysis of variance for the 3 × 3 combination is tabulated below :—

TABLE XI

*Analysis of variance for 3 × 3 combination plots*

| Source of variation | Degrees of freedom | Sum of squares | Mean square | Significance or ratio of Variance<br>Variance 2 |
|---|---|---|---|---|
| Between blocks . . . | 7 | 1326388·575 | 189484·082 | 1·403 |
| Within blocks . . . | 32 | 4319824·400 | 134994·510 | Expected 3·47 |
| Total . | 39 | 5646212·975 | | |

Standard deviation $= \sqrt{134994 \cdot 510} = 367 \cdot 41$

Co-efficient of variation $= \frac{\sigma \times 100}{\text{Mean}} = 16 \cdot 078$ per cent.

In this particular case the observed ratio of variance 1 to variance 2 being smaller than the expected ratio, no particular gain has been made by eliminating the variance due to soil heterogeneity, but this is not so in all the combinations used in this study.

Fig. 4 shows a diagrammatic representation of some of the combinations that can be formed on this experimental field on the assumption of five hypothetical treatments and the figures at the bottom of each lay-out show the number of ultimate units that have been included to form each combination plot in that series.

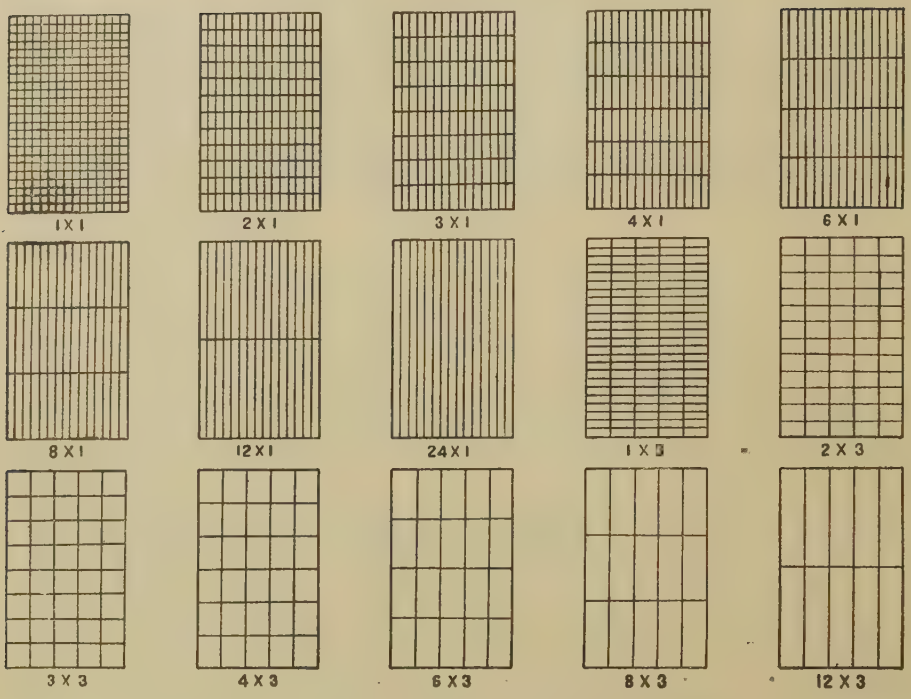


Fig. 4. Combination plots of various sizes and shapes.

Table XII depicts the analyses of variance in different combinations of Pusa 52 wheat, together with the coefficients of variations ' within plots ' for each.

## TABLE XII

*Analyses of variance in different combinations—wheat uniformity trial 1930-31*

| Combination series | Size of sub-plots' | No. of sub-plots in each combination | Variation | Degrees of freedom | Sum of squares | Mean square | Ratio of variance 1 to variance 2 | | Variation 'within blocks'. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Observed | Expected at one per cent level | Standard deviation | Co-efficient of variation |
| | | | | | | | | | | Per cent |
| 1 × 1 | 4 ft. × 4 ft. | 360 | Between blocks | 71 | 647869·53 | 9124·923 | 2·284 | 1·14 | 63·21 | 24·894 |
| | | | Within blocks | 288 | 1150630·80 | 3995·246 | | | | |
| 2 × 1 | 8 ft. × 4 ft. | 180 | Between blocks | 35 | 1114642·46 | 31846·927 | 2·835 | 1·27 | 105·99 | 20·871 |
| | | | Within blocks | 144 | 1617633·20 | 11233·564 | | | | |
| 3 × 1 | 12 ft. × 4 ft. | 120 | Between blocks | 23 | 1636175·76 | 71138·076 | 3·311 | 1·98 | 146·56 | 19·240 |
| | | | Within blocks | 96 | 2062162·40 | 21480·858 | | | | |
| 4 × 1 | 16 ft. × 4 ft. | 90 | Between blocks | 17 | 1995965·12 | 117409·713 | 3·403 | 2·45 | 185·74 | 18·288 |
| | | | Within blocks | 72 | 2483861·20 | 34498·072 | | | | |
| 6 × 1 | 24 ft. × 4 ft. | 60 | Between blocks | 11 | 2814670·58 | 255879·143 | 3·928 | 2·56 | 256·05 | 16·807 |
| | | | Within blocks | 48 | 3146996·40 | 65562·425 | | | | |
| 8 × 1 | 32 ft. × 4 ft. | 45 | Between blocks | 8 | 3700454·44 | 462556·805 | 4·269 | 3·07 | 329·13 | 16·204 |
| | | | Within blocks | 36 | 3899885·20 | 108330·140 | | | | |
| 12 × 1 | 48 ft. × 4 ft. | 30 | Between blocks | 5 | 4528666·43 | 905733·286 | 4·060 | 3·90 | 472·30 | 15·501 |
| | | | Within blocks | 24 | 5354266·20 | 223068·050 | | | | |

TABLE XII—*concld.*

| Combination series | Size of sub-plots | No. of sub-plots in each combination | Variation | Degrees of freedom | Sum of squares | Mean square | Ratio of variance 1 to variance 2 | | Variation 'within blocks' | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Observed | Expected at one per cent level | Standard deviation | Co-efficient of variation |
| | | | | | | | | | | Per cent |
| 24 × 1 | 96 ft. × 4 ft. | 15 | Between blocks | 2 | 8146081·87 | 4073040·93 | 6·958 | 6·93 | 765·10 | 12·555 |
| | | | Within blocks | 12 | 7025064·40 | 585422·03 | | | | |
| 1 × 3 | 4 ft. × 12 ft. | 120 | Between blocks | 23 | 592821·76 | 25774·86 | 1·285 | 1·98 | 141·59 | 18·590 |
| | | | Within blocks | 96 | 1924150·40 | 20043·34 | | | | |
| 2 × 3 | 8 ft. × 12 ft. | 60 | Between blocks | 11 | 862825·78 | 78438·70 | 1·167 | 2·56 | 291·89 | 19·159 |
| | | | Within blocks | 48 | 3226927·20 | 67227·65 | | | | |
| 3 × 3 | 12 ft. × 12 ft. | 40 | Between blocks | 7 | 1326388·57 | 189484·08 | 1·403 | 3·47 | 367·41 | 16·078 |
| | | | Within blocks | 32 | 4319824·40 | 134994·51 | | | | |
| 4 × 3 | 16 ft. × 12 ft. | 30 | Between blocks | 5 | 1239026·17 | 247805·23 | 1·079 | 3·90 | 465·83 | 15·722 |
| | | | Within blocks | 24 | 5508004·80 | 229500·20 | | | | |
| 6 × 3 | 24 ft. × 12 ft. | 20 | Between blocks | 3 | 1809159·35 | 603053·12 | 1·287 | 5·29 | 684·52 | 14·975 |
| | | | Within blocks | 16 | 7497123·60 | 468570·23 | | | | |
| 8 × 3 | 32 ft. × 12 ft. | 15 | Between blocks | 2 | 2269997·73 | 1134998·87 | 1·450 | 6·93 | 884·66 | 14·508 |
| | | | Within blocks | 12 | 9391625·20 | 782635·43 | | | | |
| 12 × 3 | 48 ft. × 12 ft. | 10 | Between blocks | 1 | 1147176·90 | 1147176·90 | 1·488 | 11·26 | 1306·50 | 15·387 |
| | | | Within blocks | 8 | 13655638·00 | 1706954·75 | | | | |

It will be noted from the above table that the range of the coefficients of variability extends from 12·555 per cent for the 24 × 1 combination to 24·894 per cent for the 1 × 1 combination. The best combinations that can be used for future experiments in this field appear to be 24 × 1, 12 × 3, 8 × 3 and 6 × 3, as these give the least values for their respective coefficients of variation. It must be remembered, however, that for cereals in general, a plot size approximating 1/40th of an acre is said to be ideal but in this country a good deal of work appears to be necessary to fix up the correct size of plots for different crops under the different sets of soil conditions that are met with.

## Shape of plots

An inspection of Fig. 4 will show that by taking various combinations of ultimate units, combination sub-plots of various sizes and shapes can be formed. Of these lay-outs 8 × 3 and 24 × 1 have the same plot size but different shapes and these two lay-outs also exhibit some difference in their coefficients of variation. Similarly, there are other combinations which possess the same size of plots but which differ in their shapes and in their coefficients of variability. These are enumerated below :—

TABLE XIII

*Showing the difference in the coefficients of variations in plots of equal size but of different shapes*

| Lay-out | No. of ultimate units to form each combination plot | Size of each combination plot in sq. feet | Co-efficient of variation | Difference in co-efficient of variation |
|---|---|---|---|---|
| 8 × 3 | 15 | 384 | 14·508 | 1·953 |
| 24 × 1 | 15 | 384 | 12·555 | |
| 4 × 3 | 30 | 192 | 15·722 | 0·221 |
| 12 × | 30 | 192 | 15·501 | |
| 2 × 3 | 60 | 96 | 19·159 | 2·352 |
| 6 × 1 | 60 | 96 | 16·807 | |
| 1 × 3 | 120 | 48 | 18·590 | 0·650 |
| 3 × 1 | 120 | 48 | 19·240 | |

These figures provide ample evidence to bring out the importance of the shape of the experimental plots in a given area. Plots of the same size but of different shapes have shown differences in their variability. This is chiefly due to the presence of various grades of soil fertility in the field and the inclusion of patches of unequal fertility in combination plots of varying shapes.

Lay-outs 8 × 3 and 24 × 1, for instance, are such that both divide the experimental area into fifteen equal divisions. The size of plots as well as the number of ultimate units taken to form each plot are also equal in both cases. The shape of the plots, however, differ in that in the 24 × 1 combination the field has been divided longitudinally in the direction of the columns, that is, from the north to the south, and the length of each plot is many times its breadth. In the 8 × 3 combination, on the other hand, the field has been divided into fifteen compact plots in which the ratio of length to breadth is not very great. The difference in the shape of plots in the two lay-outs has brought in a difference of 1·953 in their coefficients of variation, thus showing the superiority of the 24 × 1 arrangement over the other. It has been pointed out in the first part of this paper that the fertility gradient in this experimental field lies from west to east and that combination plots taken at right angles to this direction, *i.e.*, lying from north to south would give a smaller variability than those lying in the direction of the fertility slope. It is probably for this reason that the 24 × 1 combination, in which the plots lie in the direction of north to south, has provided the least variability.

Should the fertility slope in any experimental field be known, it is possible, then, to predict what shape as well as what size of plots would furnish the most reliable results.

## Summary

Results are reported of soil-heterogeneity experiments conducted for three consecutive years in the same field with Pusa barley, wheat and lentils.

The coefficient of correlation between contiguous plots was employed as an index of soil heterogeneity according to Harris' method, and 1 × 5 and 2 × 5 combination plots were made up for this purpose. Although the coefficients of correlation for these two kinds of combinations were not significantly different from one another, the presence of significant coefficients for each combination denotes definitely that the field under consideration was not absolutely uniform.

Fisher's analysis of variance was also employed to determine the drift in the fertility of the field with the same data. It was found that there was a great deal of variation in the yields for columns and much less in the rows, suggesting that there was a fertility gradient in this particular field which ran from west to east. This was further seen when contour maps of soil fertility were drawn from results of plot yields.

Harris' method of determining soil heterogeneity provides a measure of heterogeneity present in the whole field, but Fisher's analysis of variance not only provides a measure of soil heterogeneity but also clearly sets forth the direction of the fertility gradient and should, therefore, be a more comprehensive method for such work.

A knowledge of the amount and direction of variability in the fertility of any experimental field helps in the proper laying out of yield or manurial trials in the right direction and gives a measure of the shape and size of plot which ought to be employed. The combination which yields the least coefficient of variation within blocks in a preliminary trial is to be taken as the best one for laying out future trials in a field. The results of the uniformity trial conducted with Pusa 52 wheat have been utilized to show what size and shape in this field will produce the least variation 'within plots' on the assumption of five hypothetical treatments. The analysis of variance method is used for the interpretation of these results.

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# INFLUENCE OF TEMPERATURE AND MATURITY ON THE INCIDENCE OF SANN-HEMP AND PIGEON-PEA WILT AT PUSA

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(With two text-figures)

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## Introduction

In a recent article Mitra [1934] has shown that the wilt disease of sann-hemp, *Crotalaria juncea* Linn., is caused at Pusa by *Fusarium vasinfectum* Atkinson, and that the isolates of this fungus from wilted sann-hemp plants produce wilt in pigeon-pea, *Cajanus indicus* Sprengel, and *vice versa*. At Pusa at any rate the same *Fusarium* sp. has been found to cause wilt in these two crops. An attempt is made in this paper to show the close association existing between soil temperature and the maturity of plant and the incidence of *Fusarium* wilt in these two crops.

Numerous investigations dealing with the influence of soil temperature on plant diseases have been reported, and the literature has been exhaustively summarised by Jones, Johnson and Dickson [1926]. A review is therefore unnecessary

here except to emphasize that temperature alone is not the limiting factor of environment in the occurrence of plant diseases, but such factors as soil moisture, soil reaction and soil texture are intimately concerned and operate as a whole in limiting or favouring the causation of plant diseases. Furthermore, Jones *et al* have concluded that most of the vascular *Fusarium* wilts are favoured by soil temperatures in the neighbourhood of 24-28°C. and that the disease development-temperature curves in most cases parallel the fungus growth-temperature curves.

The work at Wisconsin and other centres was done in carefully controlled soil temperature tanks, but the results discussed in the present paper are based entirely on field data. In addition to showing that the wilt diseases of sann-hemp and pigeon-pea are influenced by soil temperature, these results indicate that the same fungus causes wilt in these two crops under two entirely different sets of conditions. In sann-hemp the incidence of wilt is favoured by soil temperatures ranging approximately from 28 to 33°C., while in pigeon-pea the occurrence of wilt is favoured by slightly lower temperatures, between 17 and 29°C., recalling the case of *Giberella saubinettii* (Mont) Sacc., which, according to Dickson [1923], causes a severe blight in wheat at relatively high temperatures, 16-28°C., and in maize at comparatively low temperatures, 16-20°C.

Maturity of plants appears to exert a good deal of influence on the incidence of wilt in the two crops under discussion as shown by the correlation coefficients that have been calculated.

## Materials and methods

Pigeon-pea and sann-hemp plants were sown in a one-tenth acre plot in alternate rows on the 14th of June 1933. The pigeon-pea used was Pusa Type 5 which has been reported by McRae and Shaw [1933] to be highly susceptible to *Fusarium* wilt. The seed of sann-hemp was secured from the Imperial Agriculturist who had collected it during the previous year from a field of sann-hemp where wilt was rather severe. The plot where these pigeon-pea and sann-hemp types were sown has, since 1923, been developed into a highly wilt-infested plot by the addition, every year, of cut pieces of wilted pigeon-pea plants and ploughing in the land so as to mix the material intimately with the soil. At the present time if a susceptible type of pigeon-pea is sown in it, hardly a plant survives at the end of the season. There were in all 490 plants of sann-hemp and 468 of pigeon-pea in the plot.

The soil temperatures were obtained by using an automatic earth temperature recorder that had been previously standardised by comparing it with a standard thermometer. Its bulb was buried at a depth of six inches in the field. The weekly mean temperatures were obtained by summating the temperatures recorded at every two-hour intervals during the week on the recorder sheets and dividing the total by 84, the total two-hour periods in the week. The well-known Pearsonian equations of simple, multiple and partial correlation were used in calculating the values of the respective coefficients.

On a fixed day in each week the plot was carefully examined and the dead plants were counted and removed. These were brought to the laboratory and each plant examined to see if the death was due to *Fusarium* wilt or *Rhizoctonia* wilt. No account was taken of the plants that had died as a result of *Rhizoctonia* attack in these calculations. The weekly percentages were calculated on the basis of the number of deaths in each week to the number living at the beginning of the particular week.

## Analysis of first set of data

### *Simple correlation between wilt incidence and soil temperature*

In Table I are recorded the weekly percentage deaths of sann-hemp and pigeon-pea plants and the weekly mean soil temperatures.

### Table I

*Percentage of weekly deaths of sann-hemp and pigeon-pea plants due to wilt*

| Age in weeks | Weekly mean soil temperature (°C.) | Sann-hemp | | Pigeon-pea | |
|---|---|---|---|---|---|
| | | Actual deaths | Percentage of deaths | Actual deaths | Percentage of deaths |
| 8 | 34 | 2 | .. | .. | .. |
| 9 | 33 | 7 | 1·5 | .. | .. |
| 10 | 29 | 20 | 4·4 | 2 | .. |
| 11 | 29 | 20 | 4·6 | 10 | 2·1 |
| 12 | 30 | 87 | 21·2 | 5 | 1·1 |
| 13 | 31 | 101 | 31·1 | 10 | 2·2 |
| 14 | 31 | 87 | 16·5 | 8 | 1·8 |
| 15 | 29 | 36 | 19·3 | 22 | 5·1 |
| 16 | 29 | 59 | 39·1 | 28 | 6·8 |
| 17 | 29 | 19 | 20·7 | 36 | 9·4 |
| 18 | 29 | 16 | 22·2 | 27 | 7·8 |
| 19 | 28 | 10 | 17·5 | 30 | 9·4 |
| 20 | 24 | 13 | 27·7 | 44 | 15·2 |

| Age in weeks | Weekly mean soil temperature (°C.) | Sann-hemp | | Pigeon-pea | |
|---|---|---|---|---|---|
| | | Actual deaths | Percentage of deaths | Actual deaths | Percentage of deaths |
| 21 | 24 | 1 | 3·0 | 18 | 7·3 |
| 22 | 24 | 4 | 12·1 | 18 | 7·9 |
| 23 | 22 | 5 | 17·2 | 64 | 30·5 |
| 24 | 21 | 2 | 8·3 | 33 | 22·6 |
| 25 | 20 | 0 | 0·0 | 30 | 26·5 |
| 26 | 20 | 0 | 0·0 | 20 | 24·1 |
| 27 | 17 | 0 | 0·0 | 17 | 27·0 |
| 28 | 17 | 1 | 4·7 | 14 | 30·4 |
| 29 | 18 | .. | .. | 6 | 18·8 |
| 30 | 18 | .. | .. | 4 | 19·2 |

After the 8th of January 1934 deaths ceased in the plot and no further readings were recorded. An examination of the data will show that while sann-hemp plants died in the earlier part of the season, those of pigeon-pea succumbed only in the latter part.

In order to determine the nature and magnitude of the correlation existing between soil temperature and wilt incidence in sann-hemp plants, the simple coefficient of correlation was first calculated. The value of '*r*' was found to be +0·537. There are twenty observations (column 4) and two variables so that the degrees of freedom are eighteen. At five per cent level of significance, the significant value of '*r*' for that number of degrees of freedom, according to Fisher [1932], is 0·444. As the value actually obtained is higher than this, it is clear that as temperature increases from 17 to 33°C., deaths due to *Fusarium* wilt in sann-hemp also increase.

A similar coefficient of correlation was also obtained for wilt incidence and soil temperature in pigeon-pea plants. The value of '*r*' in this case was found to be —0·901. This is a high value showing a very close association between soil temperature and wilt incidence in pigeon-pea plants. Apart from this, it will be noted that there is a negative sign preceding the coefficient which is indicative of the fact that wilt incidence in pigeon-pea plants at a range of temperature of 17 to 33°C. decreases as the temperature rises. In other words, the effect of soil temperature in the case of sann-hemp is to increase wilt incidence as the temperature

increases and quite the reverse in the case of pigeon-pea plants where wilt decreases as the temperature increases (always of course within the range of 17 to 33°C.).

*Simple correlation between wilt incidence and maturity of the host*

Examination of data also made it apparent that there may be some association between the maturity of plants (*i.e.*, their age in weeks) and the incidence of wilt. Simple coefficient of correlation was therefore calculated and the values of '*r*' obtained in the two cases are given below :—

| | |
|---|---|
| Simple coefficient of correlation between maturity of sann-hemp plants and incidence of wilt . . . . . | —0·314 |
| Simple coefficient of correlation between maturity of pigeon-pea plants and incidence of wilt . . . . . | +0·941 |

It will be noted that the value obtained in the case of sann-hemp does not show association being much smaller than the significant value, *viz.*, 0·444. It is negative, showing that these plants lose their susceptibility to the disease as they mature. In pigeon-pea there is very close association between maturity and wilt incidence, and as the positive sign precedes the value, the plants seem to lose their resistance to the wilt disease as they age and become more and more vulnerable to attack.

Finally, in order to show graphically the relationships of the data recorded in the table, the regression equation of soil temperature on wilt incidence and that of maturity on wilt incidence were calculated. The equations are given below and the regression lines indicating the trends are shown in Figs. 1 and 2.

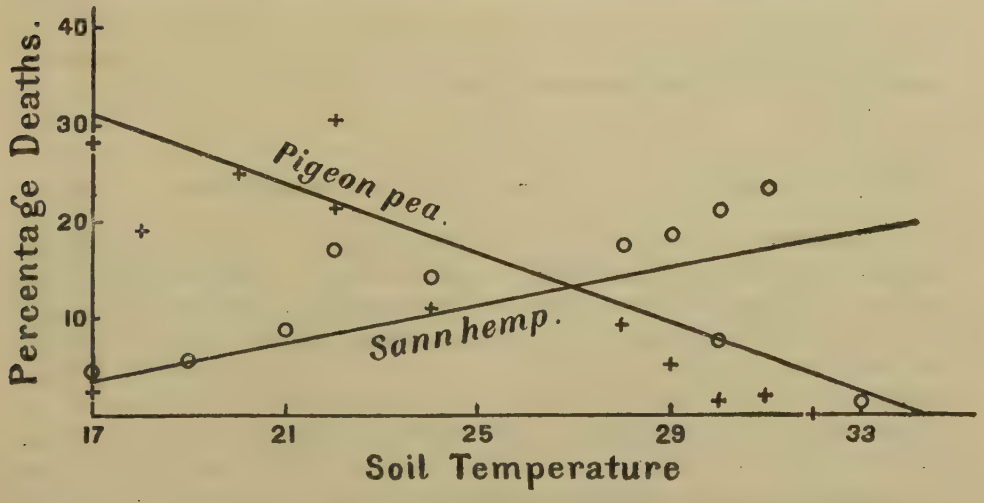


Fig. 1. Regression line showing relation between soil temperature and incidence of wilt.

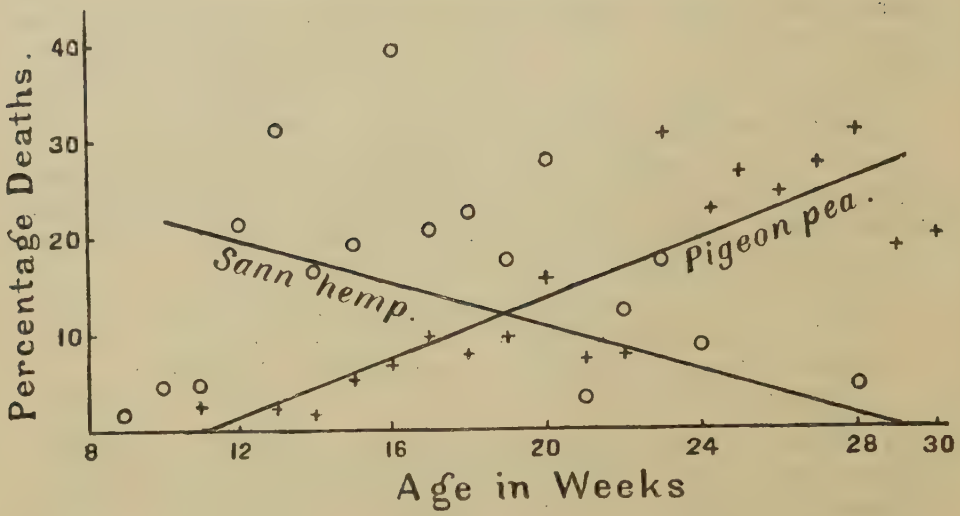


Fig. 2. Regression line showing relation between maturity and incidence of wilt

| | |
|---|---|
| Regression of wilt incidence on soil T° in pigeon-pea . . . . . | $X = 61{\cdot}7292 - 1{\cdot}795A$ |
| Regression of wilt incidenceon soil T° in sann-hemp . . . . . | $X = 0{\cdot}9375A - 12{\cdot}103$ |
| Regression of wilt incidence on maturity in pigeon-pea plants . . . . . | $X = 1{\cdot}477B - 16{\cdot}098$ |
| Regression of wilt incidence on maturity in sann-hemp plants . . . . . | $X = 33{\cdot}266 - 1{\cdot}1307B$ |

In the above equations $X$ stands for per cent deaths, A for weekly mean soil temperature and B for age of plants in weeks.

*Multiple correlation between wilt, soil temperature and maturity of the host*

It is evident from the above that, while the attempt to analyse the relations between wilt incidence and associated variables has shown interesting facts, it is possible that there is a regular network of relationships. The multiple coefficient of correlation existing between these variables, wilt incidence ( $= X$), soil temperature ( $= Y$) and maturity ( $= Z$), was therefore determined to see the nature of such relationships. This value, designated by the letter '$R$' by Pearson, was found to be $+ 0{\cdot}951$ in the case of sann-hemp and $+ 0{\cdot}943$ in the case of pigeon-pea. There are here three variables and 23 observations, so that the degrees of freedom are 20 and the significant value of $R$ at one per cent level of significance is $0{\cdot}608$ according to Table 16 of Wallace and Snedecor [1931]. These values indicate high association between these variables.

*Partial correlation between the vriables*

Finally it remained to determine whether the correlation between soil temperature and wilt continued to exist if the influence of maturity was eliminated, or between maturity and wilt if the influence of soil temperature was eliminated. Correlation coefficients between the two variables, independent of the third variable, were therefore calculated by determining the first order partial correlation coefficient. The values are given below :—

| | |
|---|---|
| First order coefficient of correlation between soil temperature and wilt, independent of maturity in sann-hemp . . | = + 0·459 |
| First order coefficient of correlation between soil temperature and wilt, independent of maturity in pigeon-pea . . | = — 0·485 |
| First order coefficient of correlation between maturity and wilt, independent of temperature in sann-hemp . . . | = — 0·437 |
| First order coefficient of correlation between maturity and wilt, independent of temperature in pigeon-pea . . . | = + 0·278 |

Here again the degrees of freedom are 20 and the significant value at one per cent level of significance is 0·608 and at five per cent level of significance 0·509, according to Wallace and Snedecor [1931]. None of the values is significant biometrically. It is apparent therefore that the influence of soil temperature and maturity on the incidence of wilt in sann-hemp and pigeon-pea at Pusa is a combined influence and not due to any one of them alone.

## Analysis of a second set of data

Data from another set of experiments were also available to test the hypothesis advanced in the previous paragraphs. In a small plot which had not been either under sann-hemp or pigeon-pea for a number of years, the soil was heavily infested with pieces of wilted sann-hemp plants collected the previous year. These pieces were intimately mixed with the soil and ploughed in before the rains in 1933. Same types of pigeon-pea and sann-hemp were sown on the 14th of June 1933. There were 503 sann-hemp plants and 278 pigeon-pea plants. Dead plants of both the crops were counted and removed every week as before. Plants which showed under the microscope that they had succumbed to *Rhizoctonia* attack have not been included in these calculations. In Table II are recorded the soil temperatures and the percentages of wilt attack, calculated as before.

TABLE II

*Percentage of weekly deaths of sann-hemp and pigeon-pea plants due to wilt*

| Age in weeks | Weekly mean soil temperature (°C.) | Sann-hemp | | Pigeon-pea | |
|---|---|---|---|---|---|
| | | Actual deaths | Per cent | Actual deaths | Per cent |
| 8 | 34 | 24 | 4·8 | 7 | 2·4 |
| 9 | 33 | 31 | 6·5 | 4 | 1·4 |
| 10 | 29 | 49 | 10·9 | 3 | 1·0 |
| 11 | 29 | 74 | 18·5 | 5 | 1·8 |
| 12 | 30 | 133 | 40·9 | 7 | 2·6 |
| 13 | 31 | 70 | 36·5 | 15 | 5·7 |
| 14 | 31 | 25 | 20·5 | 12 | 4·9 |
| 15 | 29 | 18 | 18·6 | 6 | 2·6 |
| 16 | 29 | 13 | 16·5 | 19 | 8·3 |
| 17 | 29 | 24 | 36·4 | 4 | 1·9 |
| 18 | 29 | 10 | 23·8 | 4 | 1·9 |
| 19 | 28 | 1 | 3·1 | 6 | 3·0 |
| 20 | 24 | 4 | 12·9 | 9 | 4·6 |
| 21 | 24 | 4 | 14·0 | 0 | 0·0 |
| 22 | 24 | 4 | 17·3 | 3 | 1·6 |
| 23 | 22 | 2 | 10·0 | 4 | 2·2 |
| 24 | 21 | 2 | 11·1 | 7 | 3·9 |
| 25 | 20 | 0 | 0·0 | 2 | 1·2 |
| 26 | 20 | 0 | 0·0 | 2 | 1·2 |
| 27 | 17 | 0 | 0·0 | 2 | 1·2 |
| 28 | 17 | 0 | 0·0 | 3 | 1·8 |
| 29 | 18 | 0 | 0·0 | 5 | 3·1 |
| 30 | 18 | 0 | 0·0 | 6 | 3·8 |
| 31 | 17 | 0 | 0·0 | 16 | 10·5 |
| 32 | 13 | 0 | 0·0 | 11 | 8·1 |
| 33 | 14 | 0 | 0·0 | 5 | 4·0 |
| 34 | 15 | 0 | 0·0 | 27 | 22·5 |

It will be noted, from the data recorded in Table II, that 488 out of a total of 503 sann-hemp plants succumbed to the disease, while 194 pigeon-pea plants out of a total of 287 were attacked. The first flush of deaths in the case of the former crop took place in the earlier part of the season when soil temperatures were rather high and plants were comparatively young. The deaths ceased entirely after the 24th week. In the case of pigeon-pea the plants succumbed throughout the period, more deaths however taking place in the later than in the earlier part of the season and at a time when soil temperatures were comparatively low.

In order to see the numerical relationship of these associations, the simple coefficients of correlation were also calculated, and the values are given below.

Coefficient of correlation between soil temperature and wilt incidence in sann-hemp . . . . . = + 0·170

Coefficient of correlation between wilt incidence and soil temperature in pigeon-pea . . . . . = — 0·366

Coefficient of correlation between wilt incidence and maturity in sann-hemp . . . . . = — 0·104

Coefficient of correlation between wilt incidence and maturity in pigeon-pea . . . . . = + 0·347

It will be observed that none of the values is significant, which is manifestly due to the fact that as the plot, which was not naturally infected, had been but recently artificially infested with the wilt pathogen, its index of infectivity of the soil was not as high or as uniform as that of the former plot. But the complete absence of deaths after the 24th week in the sann-hemp crop and the deaths that continued to take place in pigeon-pea support in a general way the hypothesis advanced in the first part of this paper.

## Discussion of results

Data have been presented in the preceding pages which prove that there is a close correlation between soil temperatures and the occurrence of wilt in the two leguminous crops, sann-hemp and pigeon-pea. It has been further shown that while in the former crop high temperatures favour the disease, low temperatures seem to favour it in pigeon-pea. This hypothesis has been further supported by the presentation of evidence derived from a second set of experiments.

Jones, Johnson and Dickson [1926] are inclined to the view that in the case of vascular *Fusarium* wilts soil temperatures in the neighbourhood of 24-28°C. favour the disease. While this may be true in the cases investigated by them, that does not seem to be so in sann-hemp.

In addition to soil temperature, the maturity of plants appears to exercise some influence on the incidence of wilt. The simple coefficients of correlation between wilt incidence and maturity of sann-hemp and pigeon-pea plants gave values of '*r*' which showed that while in the former crop this was partly true, it was a significant relationship in the latter case.

When multiple correlation coefficients were determined in the two cases, high values were again obtained, but the first order partial coefficients of correlation, using the data in the first table, showed that the influence of soil temperature and maturity on the incidence of wilt is not due to either of these acting independently but that it is a combined influence.

SUMMARY

1. Weekly death records in sann-hemp and pigeor-pea due to wilt caused by *Fusarium vasinfectum* Atkinson indicated that high soil temperatures, between 28 and 33°C., favoured wilt in the former and low soil temperatures, between 17 and 29°C., favoured the disease in the latter crop.

2. It was noted that the maturity of plants also exercised some influence on their susceptibility to the pathogen, more plants of sann-hemp dying in the earlier part of the season and more of pigeon-pea succumbing to the disease in the later.

3. The simple and multiple coefficients of correlation among the three variables, soil temperatures, maturity and wilt incidence, gave significant values, indicating that the hypothesis is correct.

4. It was further noted that the values of partial coefficient of correlation between wilt incidence and soil temperature, eliminating the effect of maturity, or between wilt incidence and maturity, eliminating the effect of soil temperature, were not significant, showing that the influence of soil temperatures and maturity was a combined one on these crops.

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# A NOTE ON THE INHERITANCE OF STERILITY IN COTTON

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In 1930 two sterile plants were observed in a crop of " Million Dollar " cotton grown by the Physiological Department of the Cotton Research Station, Trinidad, B. W. I. The seed from which the crop was grown had been supplied by the senior author, and was only two generations removed from the self-fertilised lines of the genetic plots. The strain is a form of *G. arboreum* (Linn.) var. *neglecta* (Watt) (as interpreted by Hutchinson and Ghose [ 1935 ]) and was obtained by Dr. S. C. Harland from Nanking, China, in 1923. The crop in which the sterile plants occurred had been carefully rogued for natural hybrids by the senior author at the beginning of flowering. The steriles were only observed late in the season, when they stood out owing to their continued flowering, and failure to set bolls. They exhibited no characters which would support the belief that they might be natural hybrids, and subsequent breeding experience with one of them confirms the conclusion that it was pure " Million Dollar".

The first sterile plant observed (known as Rogue A) was distinguished from normal plants by its very large flowers, and its complete sterility. All attempts to obtain seed by selfing or crossing, either as male or female, failed. An attempt was made to carry it on by grafting, and it was actually maintained for some months, but all grafted plants failed to produce monopodial buds, and developed into a series of straggling sympodia, which finally died off.

When Rogue A was discovered, a careful search for other similar plants was made. In a crop of about one acre, one other sterile plant (Rogue B) was found. This plant was in all respects similar to normal " Million Dollar " plants except that it failed to set bolls, and consequently remained vegetatively vigorous when fertile plants were declining as a result of the strain of boll production. On this plant, one boll set after self-pollination, and one after open pollination. Grafts

were made, and were maintained for some months. Gradually, however, one grafted plant after another developed the typical large flowers of Rogue A, ceased to produce monopodial buds, and degenerated into the bunch of straggling sympodia typical of the last stages of grafted Rogue A plants.

The selfed seeds obtained from Rogue B were sown in a greenhouse in Trinidad, and eleven plants were obtained. All were highly sterile, and no seed was obtained on selfing. Ten plants were vegetatively normal, and appeared to be typical of "Million Dollar" except for their sterility. One plant produced very abnormal, small, strap-shaped leaves, and very few small, deformed flowers. We are indebted to Dr. A. Skovsted for the information that the chromosome complement of this plant was $2n=26$, as in normal Asiatic cottons. Examination of pollen under a low power microscope showed that a very high proportion of the grains was shrivelled and collapsed.

Crosses were made between sterile plants of the progeny of Rogue B and normal "Million Dollar". Using Rogue B plants as female two successful crosses were obtained, one on plant 8 and one on plant 9. $F_1$s of ten or fifteen plants were grown, and all were completely fertile. Three $F_1$ plants were grown in the greenhouse (B. 8×M. D.-1, B. 9×M. D.-2 and B. 9×M. D.-3). Pollen of plants 1 and 2 was examined. On plant 1 all grains appeared to be normal, while on plant 2, 4 per cent of shrivelled grains only were observed. Backcrosses were made to normal Million Dollar, and selfed seed was collected. $F_2$s were grown in 1932 in Trinidad and in 1933 and 1934 at Indore, Central India. Backcross progenies were grown at Indore in 1933 and 1934. $F_3$s and backcross selfed progenies were grown at Indore in 1934. Since the amount of bad pollen gave an easily determined estimate of sterility, pollen counts were made on all plants. Details of percentage of shrivelled pollen in $F_2$, $F_3$, backcross, and backcross selfed are given in Table I.

## TABLE I

*Percentage of shrivelled pollen in crosses of Rogue B × Million Dollar*

| Generation | Family | 0-9 | 10-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 80-89 | 90-100 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_1$ | B. 8×M. D.-1 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 |
| | B. 9×M. D.-2 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 |
| $F_2$ | B. 8×M. D.-1 | 36 | 2 | ... | ... | ... | 1 | 3 | 5 | 5 | 1 | 53 |
| | B. 9×M. D.-2 | 84 | 1 | ... | ... | ... | 2 | 5 | 9 | 14 | 7 | 122 |
| | B. 9×M. D.-3 | 91 | 8 | ... | 1 | ... | 2 | 4 | 8 | 5 | 4 | 123 |
| $F_3$ | B. 8×M. D.-1-84 | 28 | 7 | ... | ... | ... | ... | ... | ... | ... | ... | 35 |
| | B. 9×M. D.-2-85 | 4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 4 |
| | B. 9×M. D.-2-86 | 4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 4 |
| | B. 9×M. D.-3-415 | 4 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | 5 |
| | B. 9×M. D.-3-412 | 3 | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 4 |
| | B. 9×M. D.-3-413 | 4 | 1 | ... | ... | ... | ... | ... | 1 | 1 | 1 | 8 |
| | B. 9×M. D.-3-418 | 5 | ... | ... | ... | ... | ... | 1 | 1 | 2 | 1 | 10 |
| Backcross | M. D. × (B. 9 × M. D.-2) | 13 | 2 | ... | ... | ... | ... | ... | ... | ... | ... | 15 |
| Backcross selfed | (M. D.×(B. 9×M. D.-2))-89 | 7 | 3 | ... | ... | ... | ... | ... | ... | ... | ... | 10 |
| | (M. D.×(B. 9×M. D.-2))-90 | 11 | 3 | ... | ... | ... | ... | 1 | ... | 2 | 2 | 19 |

The $F_2$ progeny fell into two distinct groups. In one group most of the pollen produced was bad and no seed was set either on selfing or by open pollination, while in the other group nearly all the pollen was good and the plants gave a normal crop of seed cotton.

The $F_2$ data may be summarised as follows :—

| Family | Fertile | Sterile | Total |
|---|---|---|---|
| B. 8×M. D.-1 | 38 | 15 | 53 |
| B. 9×M. D.-2 | 85 | 37 | 122 |
| B. 9×M. D.-3 | 99 | 24 | 123 |
| Total (observed) | 222 | 76 | 298 |
| (On 3 : 1 basis) | 223·5 | 74·5 | 298·0 |

The plants of the backcross were all normal, giving a low percentage of bad pollen and a normal crop of seed cotton. Two families were grown from selfed seed of backcross plants. One of them gave all fertile normal plants while the other gave fourteen fertile, with little bad pollen, and five sterile with 60-100 per cent bad pollen.

Seven small $F_3$ families were grown. Of these, four gave only fertile plants with little bad pollen, and three segregated, giving in all 13 fertile : 9 sterile plants.

The behaviour of all families agrees well with expectation on the basis of a single-factor difference between fertility and sterility, with fertility dominant. Sterility was equal on male and female sides, but was not quite complete. It thus appears to resemble in genetic behaviour Beadle's [ 1930 ] case of a gene for asynapsis in maize. The original sterile Rogue B gave one somatically abnormal plant in a progeny of eleven, the others being somatically normal. This suggests that the disturbance to gamete formation responsible for sterility has other effects also which may be manifested among what few progeny are obtainable by selfing. The somatic change which occurred in grafts of the original Rogue B, whereby they developed the characteristics of the apparently completely sterile Rogue A, are of considerable interest, but investigation of the phenomenon depends upon the success of attempts to induce similar changes in sterile segregates from heterozygous lines now under cultivation.

## Acknowledgments

The investigation here reported was commenced while the senior author was Assistant Geneticist at the Empire Cotton Growing Corporation's Cotton Research Station, Trinidad, B. W. I. He has pleasure in acknowledging his indebtedness to the Geneticist, Dr. S. C. Harland, under whom he was working, and to the Physiologist, Dr. T. G. Mason, who made available the original sterile plants.

The authors completed the work at the Institute of Plant Industry, Indore, Central India, during the tenure by the junior author of a research scholarship from the King Edward Memorial Society, Central Provinces and Berar, to which Society he takes this opportunity of tendering his thanks.

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# A NOTE ON A SURVEY OF THE DISEASE OF MALFORMATION IN THE PUNJAB-AMERICAN COTTONS

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## Introductory

For the past few years the American cottons in Lyallpur have been afflicted with a peculiar growth-abnormality. The chief symptoms of the disease have been described elsewhere [ Afzal, 1933 ] and will only be briefly reviewed here.

The chief feature which strikes the eye is the diminution of all plant organs ; the height of the plant, size of internodes, leaves, floral organs and the bolls are very much reduced in size. In addition, the leaves bear streaks of light yellow colour and appear mottled. There is fairly profuse flower-bud formation, but the shedding is likewise high and in extreme cases leads to sterility. The bolls which are formed give but few viable seeds. The attack may either be confined to a few limbs or the entire plant may be affected.

The disease was first noticed at Lyallpur on a few plants of American cotton in 1929, but continued to spread in later years and came to be reckoned as a serious disease of cotton. Up to 1933 it was only known to attack American varieties of cotton, but during this year one plant of *G. indicum* at the Cotton Research Station, Lyallpur, and two plants of *Mollisoni* at the Agricultural Farm, Sirsa, were also attacked. Since then many more plants of *Desi* cotton have been attacked.

Since its first appearance in 1929, the disease has continued to spread year after year and became a menace to cotton-growing in the Punjab Agricultural College Estate.

Diseases of cotton of a similar nature have been reported from the United States of America [ Cook ; 1913, 1924, 1927 ], West Indies [ Nowell, 1914 ], China and Haiti [ Cook, 1920, 1923 ] and Southern India [ Kottur and Patel, 1920 ]. Of late years the disease has attained serious proportions in parts of Bombay Presidency. From all outward appearances the disease in Bombay appears to be very similar to that present in the Punjab, but in Bombay it attacks the indigenous varieties of cottons, while in the Punjab the attack is mostly confined to American cottons. A careful study of the diseased plants has shown that the disease found in the Punjab is very similar to " Stenosis " or " Smalling " described by Cook [ 1924 ] and the same name has, therefore, been tentatively given to the disease.

## Extent of damage

As has been said above, the extent of the damage caused by the disease at the Punjab Agricultural College Estate has increased every year since its incipient appearance in 1929. Counts made in 1932 showed that a little over 40 per cent of the plants were attacked in certain fields. During 1933 an attempt was made to collect data regarding the occurrence of this disease in other parts of the Province, but on account of the lack of staff much headway could not be made. The Indian Central Cotton Committee were, therefore, requested to provide funds so that a thorough survey of the incidence of the disease could be made throughout the cotton-growing tracts of the province. This was undertaken in 1934 and the present note mainly embodies the results.

## Plan of work

A village-to-village enquiry was made in all the important cotton-growing tracts of the province and information collected regarding the prevalence of the disease, its time of appearance, etc. In all 138 villages were visited, but the disease was recorded from eight only, for which detailed data are given in Table I. It will be noticed that the disease was present only in a few places in Lyallpur, Multan, Lahore and Sargodha districts. It was most severe in Lyallpur, while only occasional plants were met with in the other three districts. The rest of the villages visited were found to be free from this disease.

TABLE I

*Results of survey of the disease of malformation in the Punjab-American cottons in different districts of the cotton belt*

| Names of districts | No. of villages surveyed | Area examined (acres) | | | Total | Percentage of smalling | Remarks |
|---|---|---|---|---|---|---|---|
| | | Desi | American | Desi and American mixture | | | |
| Lyallpur . . | 28 | 15 | 659 | .. | 674 | 1·014 | Includes the Punjab Agricultural College Estate, where the attack was 12·9 per cent and in some seriously attacked patches it was as much as 40 per cent. |
| Sheikhupura . . | 10 | 4 | 140 | 29 | 173 | *Nil* | |
| Gujranwala . . | 4 | .. | 26 | 27 | 53 | *Nil* | |
| Jullundur . . | 3 | 19 | .. | .. | 19 | *Nil* | |
| Hissar . . . | 7 | 128 | 3 | .. | 131 | *Nil* | |
| Gujrat . . . | 7 | .. | 111 | .. | 111 | *Nil* | |
| Jhang . . . | 12 | .. | 235 | .. | 235 | *Nil* | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Shahpur . . | 19 | .. | 307 | .. | 307 | 1·23 | Only in one locality and in one particular field the attack was up to 3·7 per cent while affected plants could be seen scattered in this field. |
| Montgomery . . | 15 | 7 | 364 | .. | 371 | *Nil* | |
| Multan . . | 11 | 29 | 277 | .. | 306 | 5·6 | Only in a ½ acre field. |
| Lahore . . . | 2 | .. | 35 | .. | 35 | .. | Only 4 plants affected in one field. |
| Amritsar . . | 6 | 72 | .. | .. | 72 | *Nil* | |
| Ferozepur . . | 2 | 10 | 1 | .. | 11 | *Nil* | |
| Karnal . . . | 3 | 25 | .. | .. | 25 | *Nil* | |
| Gurgaon . . | 5 | 45 | .. | .. | 45 | *Nil* | |
| Ambala . . | 2 | 18 | .. | .. | 18 | *Nil* | |
| Ludhiana . . | 2 | 12 | .. | .. | 12 | *Nil* | |

Detailed records were taken at the Cotton Research Station, Lyallpur, and it was found that the attack starts in July and increases progressively till the middle of September, after which there is no further increase. Figures appear in Table II.

TABLE II

*Percentage of attack at different periods of growth*

| 1932 | | 1934 | |
|---|---|---|---|
| Date of observation | Percentage of attack | Date of observation | Percentage of attack |
| 1st July . . . | 1·7 | 13th July . . . | 3·87 |
| 1st August . . . | 16·3 | 2nd August . . | 5·48 |
| 1st September . . | 42·5 | 17th August . . | 10·09 |
| | | 3rd September . . | 15·03 |
| | | 15th September . | 16·40 |

A certain degree of varietal preferences is also exhibited by the disease as the following figures will indicate.

TABLE III

*Percentage of attack on different varieties*

| Name of variety | Percentage of attack |
|---|---|
| 4 F | 10·58 |
| 43 F | 2·75 |
| 289 F | 17·46 |

Although the diseased plants are scattered about irregularly in any one field, the severity of the disease varies with different localities. The subjoined figures from fields situated in different parts of the Agricultural Research Farm, Lyallpur, show this point very clearly.

TABLE IV

*Percentage of attack in different fields*

| Variety | Square No. | Percentage of attack | Remarks. |
|---|---|---|---|
| L. S. S. . . | 27 | 20·26 | Rich land, well manured and intensively cultivated |
| 38 F . . . | 27 | 20·16 | |
| 45 F . . . | 27 | 20·61 | |
| L. S. S. . . | 32 | 3·02 | Light land |
| 38 F . . . | 32 | 4·92 | |
| 45 F . . . | 32 | 4·92 | |

The above figures are, in a way, rather remarkable. The locality in which the crop is grown seems to have a preponderating effect, while the varietal differences in the severity of attack sink into insignificance.

## NATURE OF THE DISEASE

Although similar diseases of cotton have been extensively reported from various parts of the world, their exact nature has not so far been discovered.

Likhite and Desai [1935] have discovered an excessive accumulation of starch in the stenosised organs but this accumulation of starch appears to be the result rather than the cause of the disease.

A few preliminary experiments to find out the nature of the disease were performed and are briefly described below :—

### (*a*) *Virus nature*

In order to ascertain if the disease was of virus nature the following experiments were performed :—

(*i*) *Juice inoculation.*—Ten plants of each of 4F, 289F and 43F were inoculated with an extract of diseased plants at different ages. Thus, in all 119 plants were inoculated but none of them showed any sign of disease.

(*ii*) *Grafting.*—Both the touch method and the bottle-grafting method described by Harland were used on several plants and no transmission of the disease from the diseased to the healthy branch was noticed.

### (*b*) *Possible hereditary nature*

Self-bred seed procured from the small-sized bolls borne on plants affected by smalling was sown in 1930. The resulting crop was absolutely normal in all ways and showed no attack of disease. The same experiment was repeated during 1934, the progeny of the plants showing no sign of disease. This goes to show that the disease is not of a hereditary nature.

### (*c*) *Relation of disease to soil conditions*

Different fields of the Agricultural Research Farm, Lyallpur, have, this year, shown varying degrees of attack. This points to some type of relationship between the kind of soil and the severity of the disease. More figures are, however, required to thoroughly establish this point.

## Other plants attacked by "smalling" or a disease very similar to it

An effort was made to find alternative host plants, if any, and it was found that the following crop plants were attacked by a disease which in outward appearance is very similar to the "smalling" of cotton :—

| | |
|---|---|
| *Lobia* (*Dolichos Lablab*) . . . | A very large number of plants found in cotton fields at Lyallpur. |
| *Mung* (*Phaseolus Mung*) . . . | Found in a village near Jaranwala in the Lyallpur district. |
| *Mash* (*Phaseolus radiatus*) . . . | |
| Chillies (*Capsicum annuum*) . . | Found in several plots in the Lyallpur and Ludhiana districts. |

It is suggested that an exhaustive study of the alternative host plant is likely to throw a great deal of light on the modes of perennation of this disease. This work is now in progress.

## Conclusions

The following general conclusions could be drawn :—

(*i*) The disease is serious in the Punjab Agricultural College Estate and neighbouring fields, while it is really of no consequence in the other parts of the cotton belt of the Punjab.

(*ii*) The disease primarily attacks the American varieties of cotton, while very few plants of the indigenous varieties are attacked.

(*iii*) The attack starts when the plants are about a month old. The disease is very active during August and early part of September.

(*iv*) The plants which are attacked while still young, remain very much stunted in size and bear either none or very few small bolls.

(*v*) The attack spreads upwards in the plant from the incipient focus in a fairly regular way, but sometimes a few limbs escape the effects of the disease.

(*vi*) The disease is not of a hereditary nature. It is, however, not definitely known whether it is physiological in character or a virus. Its relationship with soil conditions is likewise obscure.

(*vii*) Certain other crop plants showing symptoms similar to those of cotton have been found.

## Acknowledgments

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# INVESTIGATIONS ON THE WOUND-PARASITISM OF CERTAIN *FUSARIA*

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(With Plate XXIX)

## I. Introduction

*Fusaria* were regarded by de Bary as nothing more than obligate saprophytes. Later a large number of investigators reported the association of these fungi with various diseases of field and garden crops, but it wa Smith [1899] who first demonstrated by experiments the exact relation of *Fusarium* to wilts of cotton, water-melon and cow-pea. Duggar [1909] wrote " It is apparent that the old view which held species of the genus *Fusarium* to be largely saprophytic, must be considerably modified " and Stevens [1925] has recently remarked, " Taken as a whole the genus is one of the most injurious with which plant pathology has to do ". In India the more well-known cases of their parasitic activities are the wilts of economically important plants, such as *Cajanus indicus*, *Cicer arietinum*, *Gossypium* sp. and the rots of potatoes.

Most of the *Fusaria* collected by the writer were growing saprophytically. In view of the above remarks it was thought that an interesting result would be obtained if some of them at least showed parasitic activities. The present paper gives an account of the artificial inoculation experiments carried out on apples and potatoes with six species of *Fusarium*.

## II. Source of the *Fusaria*

1. *F. camptoceras* Wr. et Rkg.—From the ear of *bajra* (*Pennisetum typhoideum*).

2. *F. incarnatum* (Rob.) Sacc. re-named as *F. semitectum* var. *majus*. Wr.—From a darkened young shoot of *Aegle marmelos*.

3. *F. semitectum* Berk. et Rav.—From greyish spots on a green fruit of *Citrus medica*.

4. *F. diversisporum* Sherb.—From the petiole of a wilted leaf of *Carica papaya*.

5. *F. viride* (Lechm.) Wr. re-named as *F. solani* var. *medium* Wr.—From the base of the stem of a wilted *Cajanus indicus*.

6. *F. moniliforme* Sheldon.—From dead leaf sheath of *Andropogon Sorghum*.

The writer is greatly indebted to Dr. Wollenweber for identification of the species.

Bacteria-free single spore cultures grown on Brown's medium were the sources of the inocula.

## III. Inoculation of apples

The apples used were of two varieties namely the "hill" apple and the "Kashmir" apple*. They were specially selected to ensure, as far as possible, apples of the same quality and age. They were washed thoroughly in water, wiped dry and then swabbed lightly with alcohol. Inoculations were made by the method devised by Granger and Horne [1924] and used by Mitter and Tandon [1929]. Briefly the process may be described as follows.

A sterile cork-borer was thrust into the apple. It was then taken out along with the plug of the tissue of the apple and suspended over mercuric chloride solution to prevent contamination. The inoculum was placed in the cavity and the plug was replaced by pushing with a sterile glass rod passing through the cork-borer. It was then sealed with a melted mixture of paraffin and beeswax led around the margin of the plug. The inoculated apple was then rubbed lightly with alcohol and wrapped in sterile paper. A minor change, which proved useful, consisted in using a straight needle for inoculations in place of the usual hooked one. Five apples of each variety were inoculated with one species *Fusarium* and therefore 60 inoculations were made. Ten apples, five of each variety, similarly treated but not inoculated, were kept as controls. The apples were left undisturbed for 35 days at room temperature (19·5°-22·8° C.). The rots were measured by weighing the apples first, scraping out the rotted tissue very carefully and then weighing a second time. The difference between the two weighings gave the amount of rotted tissue and from the figures the percentage of damage was calculated.

* The "Kashmir" apple differs from the other in being elongated in the vertical or blossom axis, sweeter, less acidic and brighter in colour.

TABLE I

*Showing the result of inoculation of apples with* F. moniliforme *and* F. viride

| Fungus | Variety of apple used | No. of apples inoculated | No. of apples infected | Mean diameter of diseased area (cm.) | Mean percentage of rot |
|---|---|---|---|---|---|
| *F. moniliforme* . | "Hill" . | 5 | 4* | 3·8 × 3·6 | 22·32 |
| | "Kashmir". | 5 | 5 | 3·7 × 3·4 | 21·7 |
| *F. viride* . . | "Hill" . | 5 | 5 | 1·9 × 1·7 | 1·52 |
| | "Kashmir". | 5 | 5 | 1·5 × 1·4 | 1·36 |

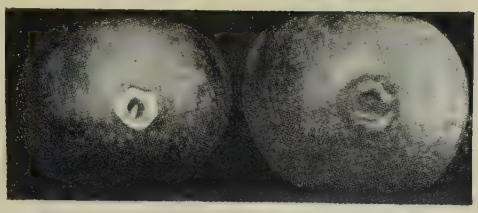
*Rot of the fifth apple was due to *Penicillium* as well as *Fusarium*.

Both the varieties of apples inoculated with *F. moniliforme* (Plate XXIX, figs. 3, 4) showed an average damage of 22·01 per cent. Those inoculated with *F. viride* (Plate XXIX, fig. 2) showed on an average only 1·44 per cent damage. Apples inoculated with *F. camptoceras*, *F. semitectum* and *F. incarnatum* and the controls remained perfectly sound and showed no signs of rot or decay (Plate XXIX). That the rots measured were due to the *Fusaria* with which apples were inoculated was proved by the isolation of the respective *Fusaria*, unmixed with other fungi, from aseptic blocks cut from the diseased part of each apple just before scraping. Only in the case of *F. moniliforme* the fifth apple of the "hill" variety showed a much greater rot and from it *Penicillum* mixed with *Fusarium* was isolated. This apple was not included in the estimation of the rot. The above experiment has been repeated with similar results, *F. moniliforme* showing a decided wound-parasitism on both the varieties of apples. Unfortunately in the second experiment no apples were inoculated with *F. viride* and so the results obtained in the previous experiment with this fungus could not be verified.

The writer has not come across any published record of the occurrence of *Fusarium* on apples in India. He is also not aware of any record of *F. moniliforme* as showing any kind of parasitic activity on apples in India.

## IV. INOCULATION OF POTATOES

Granger and Horne [1924] point out that the method of inoculation used for apples is not applicable to potatoes, for the successful removal of a plug depends on the friction between the tissue of the thing to be inoculated and the surface of the cork-borer. The tissue of potato being soapy it is almost impossible to



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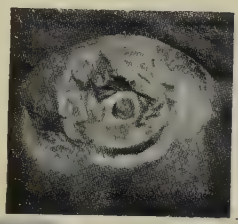

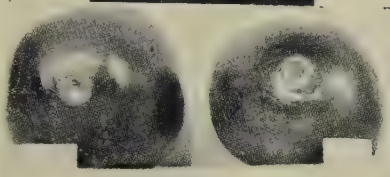

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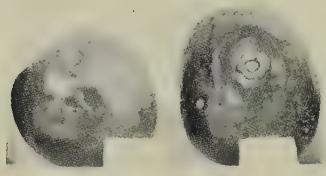

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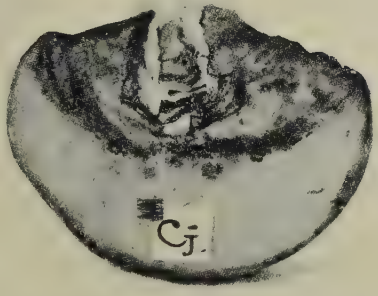


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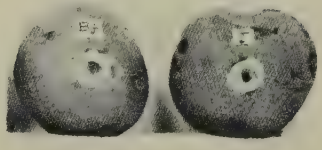

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1. "Hill" apple used as control, showing no rot. 2. "Hill" apple showing the slight rot caused by *F. viride*. 3. "Hill" apples showing the rot due to *F. moniliforme*. 4. "Kashmir" apples showing the rot caused by *F. moniliforme*. 5. Half of a potato showing the nature of the dry rot caused by *F. viride* (*Cj.*). 6. Entire potato showing the dry rot caused by *F. viride* (*Cj.*). 7. Entire potato showing the dry rot caused by the saltant No. $FV_3$. of *F. viride* (*CjS.*) 8. Potato inoculated with *F. camptoceras* (*Bj.*) showing no rot. 9. Potato inoculated with *F. moniliforme* (*J*) showing no rot.

remove an undamaged plug. For this reason the following method was adopted. The surface of a previously washed potato was swabbed lightly with alcohol. A sterile cork-borer was inserted into it for some distance. It was then taken out and the plug that remained attached to the tissue of the potato was cut half way down by the tip of a sterile pointed scalpel which was inserted obliquely at any point in the circular cut made by the borer. The detached plug was lifted up by the pointed end of the scalpel inserted in it a little sideways and the inoculum was put into the cavity. The plug was replaced and sealed with a melted mixture of paraffin and beeswax. As usual it was then wiped with alcohol and wrapped in sterile greased tissue paper. That this method is quite satisfactory is proved by the fact that out of more than fifty potatoes that were inoculated not one showed any rot due to foreign infection. Six potatoes were inoculated with a single species of *Fusarium* and six similarly treated but not inoculated, were kept as controls. They were left undisturbed for 24 days at room temperature (20°-25° C.). In this case no attempt was made to determine the amount of rot.

Result :*—

Potatoes inoculated with *F. incarnatum*—undamaged.

Potatoes inoculated with *F. diversisporum*—undamaged.

Potatoes inoculated with *F. semitectum*—undamaged.

Potatoes inoculated with *F. semitectum* saltant—$FS_1$. (This saltant originated as a sector in a Petri dish culture during a cultural study of the parent. It has been described by Mitra [1934,1])—undamaged.

Potatoes inoculated with *F. camptoceras*—undamaged (Plate XXIX, fig. 8).

Potatoes inoculated with *F. moniliforme*—undamaged (Plate XXIX, fig. 9).

Potatoes inoculated with *F. viride*—all showed heavy infection, about half of them being rotten (Plate XXIX, fig. 6).

Potatoes inoculated with *F. viride* saltant—$FV_3$. (Origin and character given in Mitra [1934,1]; showed the same damage as the parent.) (Plate XXIX, fig. 7).

Potatoes used as controls—all remained healthy and showed no wrinkles.

The rots caused by *F. viride* and its saltant were dry rots, the nature of which is shown in Plate XXIX, figs. 5, 6, 7. The rotted potatoes showed a wrinkled, sunken patch round the plug and whitish pustules were observed to come out on the surface near the plug. *F. viride* and its saltant were isolated in a pure form both from the aseptic blocks cut from the diseased parts of the potatoes and from the whitish pustules on the surface.

* A preliminary report on the parasitism of *F. viride* was published as a note entitled "A new wound-parasite of potato tubers" in *Nature* **133**, page 67: January 13, 1934.

In answer to an enquiry, Mr. S. F. Ashby of the Imperial Mycological Institute, Kew, informs the writer that he has not been able to find a record of *F. viride* on potato nor of any tests of its parasitism on that host. Recently Wollenweber [1931] has re-named this fungus as *F. solani* var. *medium* Wr. but its pathogenicity does not appear to have been tested. Out of the many investigators who have reported the occurrence of *F. solani* (Mart.) App. et Wr. on rotten potatoes only Kasai [1920] maintains that he obtained positive results with artificial inoculations. This species according to Schmidt [1928] is a saprophyte very liable to confusion with the closely related *F. caeruleum* which is known to be a virulent parasite of potatoes and according to Wollenweber [1923] is a " fast spreading inhabitant of rotting potatoes ".

## V. Conclusions

From the foregoing experiments it is seen that some of the species of *Fusarium* are restricted in their capability to parasitise different hosts. *F. camptoceras* apparently growing parasitically on *Pennisetum typhoideum* could not infect either apples or potatoes. *F. viride* could infect potatoes heavily, when wounded artificially, but showed a very weak and doubtful parasitism on apples. *F. moniliforme*, on the other hand, heavily infected apples but was unable to parasitise potatoes. The saltants did not differ from their parents in their parasitic activities on the potato. The saltant of *F. viride* was as virulent as its parent while both *F. semitectum* and its saltant lacked parasitic power. Working with *Fusarium* Mitter [1929] found that the saltants tested exhibited less virulence on apples than their respective parents.

*Fusarium diversisporum* has been shown by Sherbakoff [1915] to be a rot producer of potatoes but under the conditions of the present experiment this organism was found to be quite incapable of producing a rot.

The *Fusaria* that showed parasitic activity were mostly capable of growing saprophytically. Of such forms *F. moniliforme* is also recorded to cause corn mold disease in America by Leonian [1932]. This confirms the general experience that at least some of the *Fusaria* growing saprophytically in nature are not obligate saprophytes. Some of them under certain circumstances are able to show parasitic activity and it is possible that if they cannot infect healthy fruits and tubers, they may still cause their rots by getting into the tissues through accidental wounds.

## VI. Acknowledgment

The writer wishes to acknowledge his indebtedness to Professor J. H. Mitter for suggesting the problem and for helpful guidance.

SUMMARY

1. Six species of *Fusarium, viz., F. camptoceras, F. viride, F. diversisporum, F. incarnatum, F. semitectum* and *F. moniliforme* were tested as to their parasitic activities on apples and potatoes by artificial inoculation.

2. *F. moniliforme* was found to be able to cause a great amount of rot in both the " Kashmir " and " hill " varieties of apples.

3. Potatoes were attacked only by *F. viride* (*F. solani* var. *medium* Wr.) which caused a dry rot.

4. Saltants tested exhibited the same parasitic activities on potatoes as their respective parents.

5. As the *Fusaria* that showed parasitic activities were growing as saprophytes, it is seen, that if they cannot infect healthy fruits and tubers, they may still cause a rot by getting into their tissues through accidental wounds.

6. So far as the knowledge of the writer goes there is no published record about *F. moniliforme* and *F. viride* (*F. solani* var. *medium*) as showing wound-parasitism on apples and potatoes respectively.

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# STUDIES ON *PENNISETUM TYPHOIDES* (BURM.) STAPF. AND HUBBARD [SYN. *P. TYPHOIDEUM* (RICH)]—THE PEARL MILLET, PART II

## SPIKELET-BEARING BRISTLES*

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(Received for publication on 5th February 1935)

(With Plate XXX)

*Pennisetum typhoides* (Burm.) Stapf. and Hubbard [Syn. *P. typhoideum* Rich] is the pearl millet, '*bajra*' of North India and '*cumbu*' of Madras. The earhead of this millet is spike-like, being composed of a central rachis and a number of seriately disposed, closely-packed fascicles. Each fascicle includes one or more spikelets and a whorl of free bristles. A single spikelet is really a secondary spike having an upper and a lower floret, the former being hermaphrodite and the latter staminate, sterile or barren. Surrounding the spikelets in each fascicle there are 30-70 bristles (average 40). The outer bristles are shorter than the inner. In most cultivated varieties these bristles are not prominent. Godbole [1927] notes that the number of these bristles decreases as the number of spikelets within the whorl increases. Rare instances have been met with in which the longer individuals in this bristle group elongate much beyond the grain surface of the spike and give the earhead the hairy look associated with some of the races of the Italian (fox-tail) millet (Plate XXX, fig. 1). The occurrence and inheritance of these bristles in the Italian millet has been worked out [Rangaswami Ayyangar *et al.*; 1933,1]. The fact that some of these bristles in the Italian millet bear spikelets at their ends has been noted and the inheritance of this peculiarity studied [Rangaswami Ayyangar *et al.*; 1933,2]. In

* Paper read before the Agricultural Section of the 22nd Session of the Indian Science Congress, January 1935

Ordinary. Bristled.

FIG. 1.

Ordinary. Spikelet-bearing bristled.

FIG. 2.

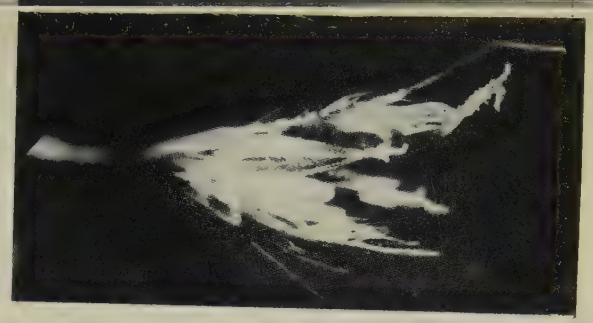

FIG. 3. Flower-bearing bristle with protruding stigma.

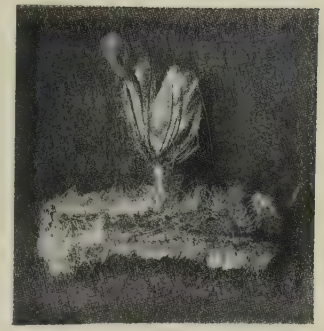

FIG. 4. Grain-bearing bristle.

PLATE XXX

some African races of the pearl millet recently received at Coimbatore, a tendency to shedding of spikelet whorls was noticed and it would appear that this disability must have militated against the perpetuation of many long-bristled types as economic varieties. Evidently the spike-like disposition of the grains is inconsistent with the accommodation of obtrusive bristles. That the reduction in bristles, both in number and in length, has kept pace generally with the packing of the grains on the earhead, will be obvious from *P. leonis* (Stapf. and Hubbard) which has the densest ear and the shortest bristles.

In the year 1928 certain bristled earheads which occurred in a collection from the Bellary District of the Madras Presidency were sown at the Millets Breeding Station. In five of the plants raised, odd bristles were noted to have floral parts attached to their ends. These were first suspected to be dry anther sacs sticking on to the bristles, but later on were found to be definite out-growths from the latter (Plate XXX, fig. 2). These bristles were obviously continuations of the fascicle axis and bore the spikelets at the ends as lateral appendages. Beyond these appendages, the bristle got prolonged, but by the shedding of the prolongation at maturity the spikelet appeared as the apparent end of the bristle (Plate XXX, figs. 3 and 4). The occurrence of the spikelet-bearing bristles was however noted only in comparatively short-bristled earheads. Seeds from such earheads were sown and in the year 1930, out of 337 plants thirty-one showed these abnormalities. Two of these earheads were selfed and in 1931 when these were sown, forty-nine out of 166 manifested this abnormality. The increase in number is not surprising in the selfed material of this protogynous crop. Two heads were again selfed and in the 1932 crop ninety-eight out of 200 plants had earheads showing stray bristle-bearing spikelets. A detailed analysis of this population was made in that year. It was noticed that there was a total of 673 earheads and of these 309 had spikelet-bearing bristles. In these 309 heads, the number of such spikelet-bearing bristles was on an average twenty, with a range from one to sixty per head, though in odd cases it went up to a hundred. Of these spikelet-bearing bristles all the spikelets at the ends were examined and it was noticed that only 166 bore grains out of a total of nearly 3,500 spikelets. These grains had eighty-eight per cent of germination while the ordinary grains had ninety-five per cent. They weighed half the weight of an equal number of normal grains.

These results show that the more prominent of these bristles are the prolongation of the fascicle axis with stray tendencies for developing lateral spikelet appendages a little below the apex. That they could have normal spikelets in rare instance has been shown above. The reference of Hofmeister to bristles bearing glumes is not clear. If there were indications of these glumes, a wider search would have led to the detection of at least weak spikelets on some of the bristles. Arber [1931] does not favour Hofmeister's view but is inclined to regard the ultimate bristle-shoots as equivalent to spikelets. The

existence of these spikelets with their usual complements of hermaphrodite and sterile flowers on the more prominent of these bristles, leads one to conclude that these grain-bearing bristles are prolongations of the fascicle axis. This phenomenon will, we expect, throw fresh light in the interpretation of histological data through which the origin of these structures has till now been sought to be pursued.

These spikelet-bearing bristles have also occurred in other imported varieties both African and Indian. Their occurrence in their new habitat may add weight to isolated observations in respect of other latent characters and may be considered as part of the reactions consequent on new place effect.

## Summary

In *Pennisetum typhoides* (Stapf. and Hubbard)—the pearl millet, spikelet-bearing bristles have been met with. Their examination sets down the bristle as the prolongation of the fascicle axis. The spikelet is borne as lateral appendage, near the end of this prolongation.

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# ABSTRACT

**The Storage of Avocado Pears.** C. W. Wardlaw and E. R. Leonard.

(*Mem. No. 1 of the Low Temperature Research Station of the Imperial College of Tropical Agriculture, Trinidad, British West Indies.*)

The following are extracts from the above paper :—

### Introduction

In preliminary studies relating to the storage behaviour of West Indian avocado pears (1), it was found that the majority of local " varieties" were unsuitable for refrigerated transport overseas because of their tendency to chill at temperatures insufficiently low to retard maturation processes. The fact that a few " varieties " were sufficiently cold-resistant, however, indicated that further storage trials might be undertaken with useful practical results. Accordingly, during the avocado season of 1934, a comprehensive series of storage experiments was again carried out, the results of which are summarised below. With a view to elucidating peculiarities in the physiological behaviour of this fruit during ripening, investigations into the nature of respiration, chilling, tolerance of gas-storage and relevant biochemical aspects have also been commenced.

### General observations

Anticipating, for the sake of greater clarity, observations and conclusions substantiated in later sections, some general characteristics of West Indian avocado pears may be briefly mentioned at this point.

1. With very occassional exceptions (*e.g.*, the *Pollock* variety), West Indian avocados are of seedling origin and show a striking range in variation in a number of important characteristics :

(*a*) shape may vary from small sub-spherical fruits to elongated bottle-necked fruits of large size ;

(*b*) colours include dark green, pale green, yellowish green, and purple ;

(*c*) the skin may be thick or thin, waxy or dull, rugose or smooth, relatively soft in texture or distinctly woody ;

(*d*) flesh colour varies from a medium yellow to pale greenish-white ;

(*e*) leaving aside questions of palatability which are difficult to define, but which may range from an insipid, floury to a rich nutty flavour, the flesh may vary in the matter of oil-content, development of fibre and thickness ;

(1) " Preliminary Observations on the Storage of Avocado Pears ", by C. W. Wardlaw, *Tropical Agriculture*, XI, No. 2, pages 27—35, 1934.

(*f*) variations are also readily apparent in the size and shape of the stone its proportion to the total weight of the fruit, and the nature of its insertion, *i.e.*, loose or adherent to the flesh.

2. During cold storage, even at relatively low temperatures, maturation processes slowly continue so that fruits ultimately become ripe and finally over-ripe. In the few varieties which are sufficiently cold-resistant or tolerant of low temperatures, such ripening apparently takes place in a more or less normal manner, the flesh at maturity being of good flavour and free from internal breakdown, discolouration or other obvious abnormalities. On the other hand, in the majority of varieties, *i.e.*, those which do not possess adequate cold-resistance, maturation processes also continue but it is evident that the metabolic trend is abnormal. Thus, although such fruits eventually become soft in cold storage, inspection of the flesh at once shows that chill effects have been induced. The range in genetical constitution outlined above is strikingly exemplified in the matter of cold-resistance : this extends from varieties subject to chilling after 15 days at 53°F. to those which ripen normally during 40 days at 40°F.

3. A comparable though not necessarily parallel variation in response to gas-storage conditions has also been observed : this ranges from fruits which mature normally after treatment to atmospheres containing sub-normal oxygen or high carbon dioxide concentrations, to those in which pronounced pathological symptoms are induced by such treatments.

4. Considerable differences are also apparent in the rates of ripening of different varieties under controlled conditions and in their subsequent keeping quality.

5. Variations in genetical constitution are reflected in the resistance of different varieties to anthracnose and to other storage diseases : this ranges from fruits which are severely affected in the field prior to reaping to those in which little wastage develops even after prolonged storage. So far susceptibility to fungal pathogens has not been correlated with any particular type of rind.

6. In general, the collective genetical characters of West Indian avocado pears and the impress of climate and environment are such that the behaviour of varieties in cold storage shows marked departures from the records obtained by investigators elsewhere.

* * * * * * * *

## Summary and recommendations

1. An account is given of further investigations into the cold storage behaviour of West Indian avocado pears, with a view to preparing the way for an export industry to Canadian and British markets.

2. West Indian avocado pears show a striking range in variation in colour, shape, size, texture of skin, proportion of stone to pulp, colour and fibre-content of pulp and in palatability. When fruits are placed in cold storage this genetic variability is further reflected in differences in keeping quality, susceptibility to fungal pathogens, rate of ripening and to tolerance of low temperatures.

3. In confirmation of earlier investigations, it was again found that a large majority of Trinidad varieties do not possess the keeping quality and are not sufficiently cold-resistant to be held for normal commercial periods (16-25 days) at 45°F. At this temperature such varieties are subject to chilling, with concomitant discolouration of the pulp and in some instances of the skin. On the other hand, if these varieties are kept at higher temperatures, *i.e.*, above the chilling temperature, consignments are liable to become over-ripe before the normal and relatively brief storage period has elapsed. It follows, therefore, that in developing avocado orchards and in organising an export industry, only those varieties should be used which are known to possess adequate cold resistance. In practice, this means that the majority of avocado types scattered throughout the West Indies, though excellent for local consumption, should not be used for export. This leaves a relatively small minority possessing the low temperature resistance and keeping qualities necessary for establishing West Indian fruit on distant markets. Thus, from current investigations, *it is recommended that some or all of six varieties should be used during the coming avocado season for trial shipments, the fruits to be picked full-grown, but quite firm, or in colouring varieties, full-grown but green, suitably packed and protected in slatted crates and transported at a steady temperature of 45°F. These stocks should also be used for propagating purposes. Casual shipments of varieties not adequately tested for keeping quality and low temperature resistance should be discontinued: not only are such consignments almost certain to arrive on distant markets in bad condition and thereby create prejudice against West Indian produce, but repeated failures will also result in the discouragement locally of a possible export industry.*

4. The phenomenon of chilling in avocado pears presents points of considerable scientific interest. It may be manifested in different ways in different varieties. A notable feature of chilling at the storage temperatures used is that complete killing of the internal tissues as a result of over-refrigeration does not take place. On the contrary, maturation processes continue but follow an abnormal biochemical trend, finally culminating in the production of a soft but darkened pulp of poor flavour. It has been shown that the onset of chilling is closely associated with ripening processes, when the fruit, which is then passing through a critical stage, is apparently more subject to modification under the impact of external factors.

5. As anticipated in earlier researches, certain varieties lend themselves to preservation by gas-storage methods. Here again, however, a considerable range in variation is apparent, some varieties being intolerant of high concentrations of $CO_2$ or low concentrations of $O_2$. In extension of this aspect of preservation, fruits were smeared with different substances to determine if ripening could be delayed without injury to the fruit. The results obtained show that the application of relatively impermeable substances definitely delays ripening. Further search for a suitable coating is, however, necessary, as those so far tested limit gaseous interchange to an extent inimical to normal ripening.

# NOTES

## FACILITIES FOR TRAINING AT THE TECHNOLOGICAL LABORATORY, MATUNGA, BOMBAY

As in the past the Technological Laboratory will admit this year two students for training in the elements of spinning and the routine methods of testing cotton fibre and yarn. The selected candidates will be expected to join on the 2nd December 1935 and will conform to the Laboratory regulations regarding hours of work, etc. The course normally lasts for a period of six months and a fee of Rs. 50 only will be charged for the full course.

Candidates desirous of admission should submit written applications to the Director, Technological Laboratory, Matunga, Bombay, so as to reach him not later than the 1st November 1935.

## THE WOODHOUSE MEMORIAL PRIZE

The following announcement has been received from the Director of Agriculture, Bihar and Orissa :—

In memory of Mr. E. J. Woodhouse, late Economic Botanist and Principal of Sabour Agricultural College, who was killed in action in France in 1917, a biennial prize in the form of a silver medal and books of a combined value of Rs. 100 will be awarded to the writer of the best essay on a subject of botanical interest to be selected from the list noted below. The length of the essay should not exceed 4,000 words.

The competition is open to graduates of Indian Universities and to Diploma-holders and Licentiates of recognised Agricultural Colleges in India who are not more than 30 years of age on the date of submission of their essays.

Papers should be forwarded to the Director of Agriculture, Bihar and Orissa, Patna, before November 1st, 1935.

Failing papers of sufficient merit no award will be made. Essays must be type-written on one side of paper only.

1. Intergeneric hybrids and their importance to agriculture.
2. The problem of rust of wheat in India.
3. The constancy of agricultural and botanical characters of paddy and their suitability for being used in a scheme of classification.
4. Rotation of crops in relation to the eradication of weeds.

## THE MAYNARD-GANGA RAM PRIZE

In 1925 the late Sir Ganga Ram, Kt., C.I.E., M.V.O., R.B., Lahore, with that generosity for which he was so well known, handed over to the Punjab Government a sum of Rs. 25,000 for the endowment of a prize of the value of Rs. 3,000 to be called the Maynard-Ganga Ram Prize and to be awarded every three years, for a discovery, or an invention, or a new practical method which will tend to increase agricultural production in the Punjab on a paying basis. The competition is open to all throughout the world. Government servants are also eligible to compete for it.

Entries for the next award were invited by the 31st December, 1933. None of the entries was considered to be of sufficient merit and it has been decided by the Managing Committee of the prize that the award should be postponed for another year and that further entries should reach the Director of Agriculture, Punjab, Lahore, on or before the 31st December, 1935.

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Applications are invited for " The Maynard-Ganga Ram Prize " of the value of Rs. 3,000 which will be awarded for a discovery, or an invention, or a new practical method tending to increase agricultural production in the Punjab on a paying basis. The prize is open to all, irrespective of caste, creed or nationality, and Government servants are also eligible for it. Essays and theses are not eligible for competition. The applicants should prove that some part of their discovery, invention, etc., is the result of work done after the prize was founded in 1925. The Managing Committee reserves to itself the right of withholding or postponing the prize, if no satisfactory achievement is reported to it. All entries in competition for the next award should reach the Director of Agriculture, Punjab, Lahore, on or before the 31st December, 1935.

## MEETING OF THE PERMANENT COMMITTEE OF THE INTERNATIONAL INSTITUTE OF AGRICULTURE

The Permanent Committee of the International Institute of Agriculture at its Summer meeting recently concluded, after disposing of several questions of internal interest treated other subjects of an international order.

The Committee resolved to collaborate with the Hygiene Organisation of the League of Nations, with the object of arranging an International Exhibition of Rural Housing, to be held in Rome under the auspices of the Italian Government in 1936.

It also made certain modifications in the regulations for the Agricultural Economic Committee, one of the Institute's consultative organs, in order to secure more expeditious working, and received a report on the results of the International Diplomatic Conference for the standardisation of the methods of wine analysis in international trade, results to which considerable publicity has already been given.

In addition the Permanent Committee approved the report of the last meeting of the Joint Agricultural Consultative Committee held at Geneva, 28-29 May. This body is an organ of Liaison between the Institute at Rome and the International Labour Office.

The Committee also arranged for the representation of the Institute at various International Congresses to be held during the summer and autumn of the current year, and decided to invite the Cth International Congress of Horticulture to use the assembly hall and committee rooms of the Institute for the purposes of its forthcoming meeting.

# NOTICE

Copies of the undermentioned publications are available for free distribution, provided the cost of packing and postage or railway freight is met by the indentor. Application should be made to the Secretary, Imperial Council of Agricultural Research (Publication Section), Imperial Record Department Building, New Delhi :—

1. Manual of More Deadly Forms of the Cattle Diseases in India (1903). 3rd Edition.
2. Notes on the Cattle of Mysore, by A. Kristnasamiengar and Captain H. T. Pease (1912).
3. The Indigenous Breeds of Cattle in Rajputana, by Major F. S. H. Baldrey (1911).
4. The Fodder Grasses of N. India, by Duthie.
5. Some experiments in the treatment of surra in camel (1913).
6. Treatment of surra in horses by means of arsenic and its derivation.
7. Cure of surra in horses by the administration of arsenic.
8. Immunization against Charbon Symptomatique by means of a single vaccine (1909).
9. Report on the experiment carried out to test the susceptibility of cattle for several diseases and on improved method of rinderpest serum preparation (1913).
10. Flax in India, by Robert S. Finlow (1918).
11. Catalogue of Ferns in the Herbarium of the Government of India at Saharanpur (1890).
12. Agriculture in India, by James Mackenna (1915).
13. Report of Mr. C. S. Marten on the Foreign Market for Indian Timber (1927).
14. Report on the extension of cinchona cultivation in India, by Lt.-Col. Gage.
15. Catalogue of the " Plants of Kumaun ", by Sir Richard Strachey and Duthie.
16. Report of the Proceedings of the Second Entomological Meeting (1917).
17. Report of the Proceedings of the Fifth Entomological Meeting (1924).
18. Review of Agricultural Operations in India, 1919-20 to 1921-22 and 1923-24 to 1928-29.
19. Report on the progress of Agriculture in India, 1907-09, 1909-10, 1911-12 to 1918-19.
20. Memoirs of the Imperial Department of Agriculture in India.
    (*a*) Botanical Series
    (*b*) Bacteriological Series
    (*c*) Chemical Series
    (*d*) Entomological Series
    (*e*) Veterinary Series
    } Most of the back numbers are available and can be supplied as far as possible.
21. Agriculture Journal of India
22. Journal of the Central Bureau for Animal Husbandry and Dairying in India.
    } Ditto.
23. Notes on the collection and preservation of entomological specimens : Study of life history of insects, by Stebbing (1901).

## ERRATA

*The Indian Journal of Agricultural Science.*

Vol. V, Part IV, August 1935

Page 543, lines 10 and 11, the title of this note should read "Importation of 'Mexican Jumping Beans' into India". (This Notification of the Government of India in the Department of Education, Health and Lands, No. F. 145/35, dated the 23rd April 1935, relates to the whole of British India including Burma and not to Burma only.)



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